G.E.C. JOURNAL

VOLUME 24 Number 4 OCTOBER 1957

THE GENERAL ELECTRIC COMPANY LIMITED OF ENGLAND

Volume 24, number 4

OCTOBER, 1957

G.E.C. JOURNAL

CONTENTS

Page

166 The power house, built and equipped by the G.E.C. under a comprehensive contract, at the new Ravenscraig iron and steel works of Colvilles Ltd.

167 Developments in Power Rectifiers
1.—Introduction
By L. J. C. Connell

169 Developments in Power Rectifiers
2.—High-voltage Rectifiers
By K. G. Cook

174 Three-phase A.C. Distribution for Ships' Auxiliaries
By W. R. Cox

186 Jamadoba Central Coal Preparation Plant, India
By H. G. Hague and Philip Rabone

195 New Trains for Suburban Routes in the London Midland Region
By J. C. Turrall and W. E. Lewis

201 "Im-Plast"—A New Toughened Rubber Material for Battery Containers
By A. L. Sparshott

206 Technical Literature

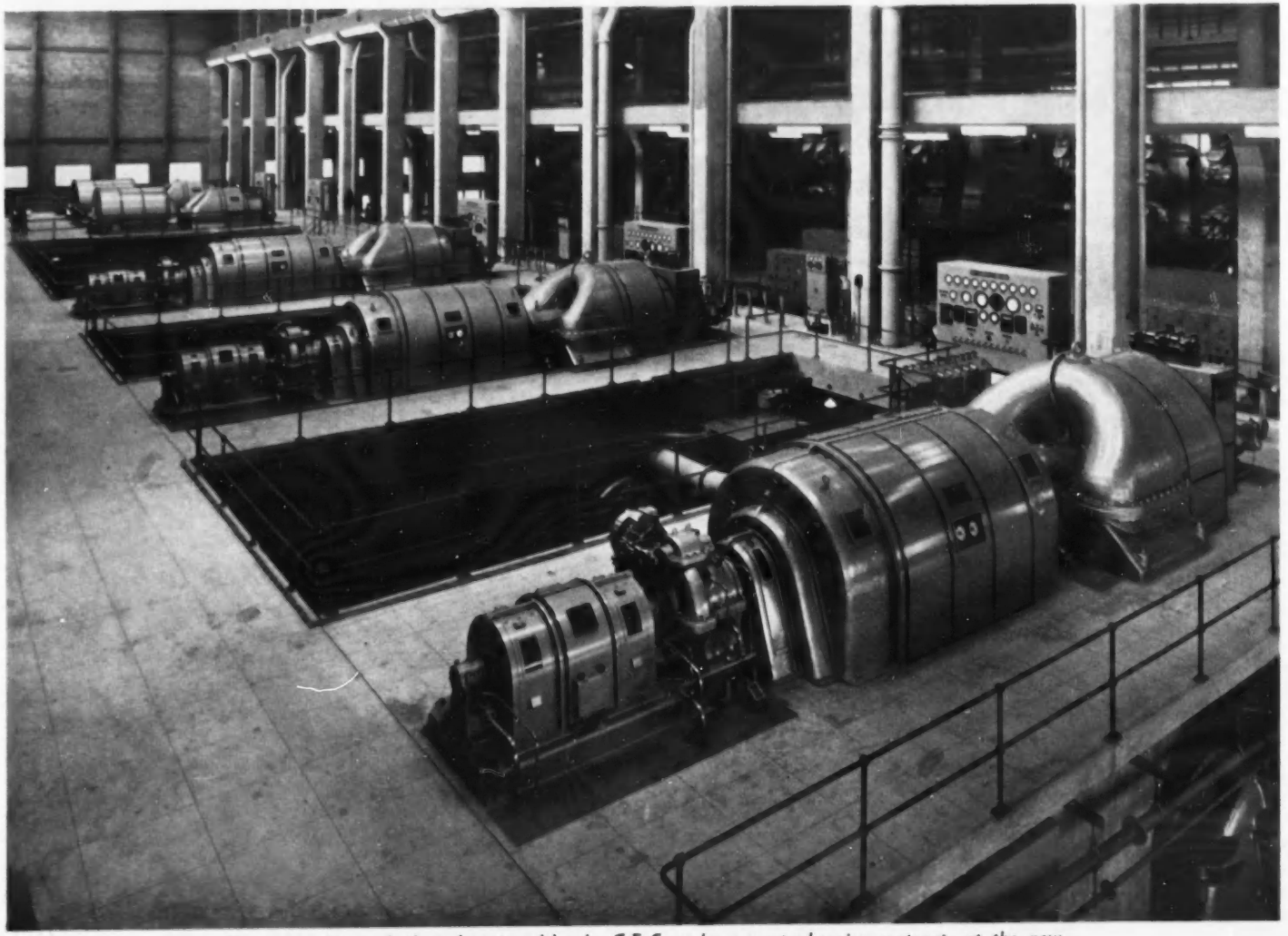
COVER PICTURE

The 8 ft. × 8 ft. supersonic wind tunnel at the Royal Aircraft Establishment, Bedford, where the air flow in the working section is regulated by the flexing of 1 in. thick steel plates actuated through a G.E.C. supervisory control system.

Published by
THE GENERAL ELECTRIC CO. LTD.
Magnet House, Kingsway, London, W.C.2

Copyright

Printed by The Hollen Street Press, Ltd., London, W.1



The power house, built and equipped by the G.E.C. under a comprehensive contract, at the new Ravenscraig iron and steel works of Colvilles Ltd.

Developments in Power Rectifiers

1.—INTRODUCTION

By L. J. C. CONNELL, B.Sc., A.Inst.P.,
Research Laboratories.

In this issue we begin publication of a series of articles dealing with low, medium and high voltage power rectifiers. The introductory survey below recalls how the increase in electrical generation in this country and the growing demand from export markets have resulted in more and larger rectifiers being built to meet the many industrial and other requirements for d.c. power, accompanied by far-reaching developments in design and the introduction of entirely new types. It is followed by an article dealing with high voltage rectifiers. Low and medium voltage rectifiers will be discussed in a subsequent issue.

IN the series to which this article forms an introduction, developments in "low", "medium" and "high" voltage ranges of power rectifier are reviewed separately. The term "power rectifier" has different meanings in industrial power supply circles and in the radio engineering industry; it therefore needs definition, as also do the voltage ranges into which the applications of the rectifiers are divided. Radio receiver and other relatively low power uses are outside the scope of the articles and the field covered, in terms of d.c. voltage and current, is broadly as follows:

Low voltage	*Medium voltage*	*High voltage*
Up to 250 V	250 V to 2-3 kV	2-3 kV and above
50 A and above	10 A and above	0·25 A and above

In all three voltage ranges there are many important industrial and other applications in which direct current is required. The chemical industry, the metal refining, processing and finishing industries and electric traction undertakings are by far the biggest users of d.c., with requirements spread over low and medium voltages. In the high voltage field, the applications are more specialised and arise mainly in d.c. power units for radio and television transmitters, industrial high frequency heating equipments, electromedical apparatus and electrostatic precipitators.

With low and medium voltage applications providing most of the demand, the rectifiers in widest use are of types having electrical characteristics and other properties making them specially suitable for operation in these ranges. These are the mercury arc rectifier and the so-called "metal" rectifier (selenium supplying practically all the demand in the latter class).

The field of use for each is determined by a number of considerations, of which operating efficiency is one of the most important. No rectifier is a perfect conductor in the forward or conducting direction or a perfect insulator in the reverse or blocking direction, and for all rectifiers there is an upper limit to the reverse voltage which can safely be applied. The main loss in the rectifier is caused by the forward voltage drop and this is much greater in a mercury arc discharge than in a single selenium element. On the other hand, the mercury arc rectifier will withstand a very much higher reverse voltage. The broad effect of this is that in most low voltage applications, where it is unnecessary to have more than a small number of selenium elements in series to withstand the reverse voltage, selenium rectifiers are used; the loss, due to the total forward voltage drop, is still less than would be obtained with the mercury arc rectifier. In most medium voltage applications, the mercury arc rectifier is used.

Factors other than efficiency can affect the choice—for example, simplicity of transformer design and absence of auxiliary equipment can favour selenium while ability to obtain variation of output voltage by means of grid or phase control can favour the mercury arc rectifier. These and other aspects are considered in later articles in this series and it is sufficient to note here that selenium rectifiers are sometimes also used at medium and high voltages, and that the mercury arc rectifier is used at high as well as at medium voltages. Other types of rectifier for use at high voltages are the vacuum valve rectifier and hot cathode rectifiers usually with fillings of mercury vapour or xenon.

It is not possible to give complete and up-to-date figures for production and usage of the different types of rectifier but some information on output in those years for which there was a census of production is obtainable from the census reports issued by the Board of Trade. The most recent of these, for the year 1951, gives the particulars shown overleaf of sales of mercury arc and metal rectifiers in that year. Some rectifiers may have escaped inclusion under the main classification and have been entered instead among battery chargers, electroplating plants or welding machines but

RECTIFIER SALES IN 1951.*

Type of rectifier	Value of sales of rectifiers produced in the United Kingdom		
Mercury vapour (glass bulb and steel tank)	Complete rectifiers	£2,826,000	£2,920,000
	Parts	94,000	
Metal	Complete rectifiers	477,000	£678,000
	Parts	201,000	

this is unlikely to have altered the general picture, which is that much the greater part of the total demand, in terms of money value, was filled by the mercury arc rectifier. There are no comprehensive figures for rectifier output ratings but the census returns suggest that the totals in 1951 approached 500 MW for mercury arc rectifiers and were less than one tenth of this for selenium power rectifiers. However, these figures, taken on their own, can give a misleading impression of the relative usage of the two types. Most selenium rectifier equipments have comparatively low voltage and power ratings (though some have quite high current ratings), and the applications for them are more numerous and widespread than a comparison of money values or power outputs might suggest.

Today, with an increase since 1951 of 45 per cent in the amount of electricity generated in this country and an increased demand from export markets, more and larger rectifiers are being built. Superficially, for the bulk of applications, the position is very similar to that in 1951 with mercury arc and selenium rectifiers in widest use. But far-reaching developments which have been taking place in rectifier design are now resulting in the introduction of entirely new types as well as improved versions of established ones.

The most outstanding of the developments is undoubtedly the single crystal semiconductor rectifier. With its promise of simplicity, high efficiency, compactness and long life and with its ability to occupy easily a position in the voltage range where the fields for selenium and mercury arc overlap, it presents a great challenge to these established rectifiers. It has stimulated development work already in progress on them—work aimed at securing a greater efficiency, longer life, higher maximum operating temperature and higher reverse voltage rating for the selenium rectifier and a greater efficiency and smaller size for the mercury arc rectifier.

An interesting situation is now developing and the pattern of rectifier usage for some years to come will be determined by the results of the investigations now proceeding. These will show how far the electrical characteristics (especially the peak inverse voltage ratings) of the single crystal semiconductor rectifiers can be improved and how quickly methods for making the rectifiers reliably and cheaply in quantity can be perfected. The relative progress with the single crystal, the selenium and the mercury arc rectifiers will determine how far the new types will supplant the established ones in their respective fields.

Already, the germanium rectifier has progressed to the extent where it is at least doubtful whether another comparatively recent introduction—the mechanical contact rectifier—will be widely adopted in industry. This rectifier, developed mainly on the Continent, incorporates synchronously-operated switching contacts which connect and disconnect the a.c. input and d.c. output terminals in a carefully controlled way during each cycle. It has come into limited use during the last ten years or so, primarily for high current electrochemical duty at 100-500 V. Its main advantage is its high efficiency. In this respect the germanium rectifier will now give a closely comparable performance, with advantages in simplicity, compactness and absence of moving parts.

Additional stimulus for development in the medium voltage field is provided by the British Transport Commission's vast modernisation programme for British Railways. With the new 25 kV a.c. overhead distribution system, rectifiers of substantial capacity will be installed on the rolling stock to provide d.c. for the driving motors. The requirements are stringent. Space is limited in volume and shape and so the rectifiers must be compact. They must be capable of operating over a wide range of line voltages and must be able to provide the overload currents called for under starting conditions and during operation on gradients. They must be robust, reliable and reasonably efficient and must be able to work under extremes of weather conditions.

In applications in other voltage ranges, the demands can be equally exacting. Thus for high voltage rectifiers, high efficiencies, short warming-up times, good shelf storage properties, long lives and the ability to operate over a wide range of ambient temperatures are required to a greater or less degree in different applications.

In rectifier engineering, as in many other fields, if the maximum benefit is to be derived from development work, the development engineer must have a good understanding of the user's problems and requirements. The articles which follow are written with the user's interests in mind. They are intended to provide him with a picture of the present situation in power rectifier development and the prospects for future advances in the particular voltage range in which his interests lie.

* The Report on the Census of Production for 1951, Vol. 4. Trade K, p.4 K/7 (H.M.S.O., 1956).

Developments in Power Rectifiers

2.—HIGH VOLTAGE RECTIFIERS

By K. G. COOK, B.Sc.(Eng.)
Research Laboratories.

IN the high voltage field of power rectification, which was defined in the introductory article as including d.c. output voltages above 2 kV and currents above 250 mA, there are several rectifier types available to an equipment designer. Hot cathode vacuum valves, hot cathode gas-filled valves, mercury pool rectifiers, and selenium, germanium or silicon solid state rectifiers are all suitable for use in the construction of high voltage d.c. power supplies.

The physical processes by which rectification is achieved in the different types are vastly different and, as a result, the secondary properties of the rectifiers are also very different. These secondary properties will largely influence a designer in his choice of rectifier for a particular application.

HIGH VOLTAGE D.C. POWER SUPPLIES.

High voltage power rectifiers are most widely used to provide d.c. supplies for vacuum oscillator valves such as triodes, magnetrons, klystrons or travelling wave tubes, the power requirements of which vary enormously. A radio transmitter might require anything from 1 A at 2 kV to 20 A at 15 kV, while for a television transmitter 10 A at 7 kV is typical. High frequency induction heaters require power supplies similar to those for radio transmitters. In radar modulators, the circuits most commonly used incorporate d.c. charging of the pulse-forming network and here power supplies ranging from 250 mA at 5 kV to 3 A at 15 kV are required. High voltage d.c. supplies are also needed for electromedical apparatus, particle accelerators and electrostatic precipitators. A newer requirement has arisen with the use of high d.c. voltages for the separation of mineral ores.

THE SECONDARY PROPERTIES OF RECTIFIERS.

Before the different types of rectifier are described, it will be useful to consider the various secondary properties which might influence a designer in his choice. The efficiency of a particular rectifier will depend on the following factors :

(*a*) the " figure of merit " of a single rectifier element and the peak inverse voltage required ;
(*b*) the power losses in the auxiliary equipment associated with the rectifier ; and
(*c*) the transformer connections in the rectifier circuit.

The " figure of merit " of a single rectifier element may be defined as the ratio of the maximum peak inverse voltage which the element will withstand to the voltage drop at full load current. The figure of merit for solid state rectifiers at the present time ranges from about 30 to 400, e.g. a maximum peak inverse voltage of 30-400 volts and a forward voltage drop of 1 volt. For rectifiers using gaseous discharges the ratio is about 700 to 1,800, e.g. 10-25 kV peak inverse and a drop of about 14 volts.

Where the rectifier circuit demands a high peak inverse voltage, then solid state rectifiers must be operated in series. There is then a critical inverse voltage, which will not exceed a few kilovolts, at which the voltage drop of 14 solid state rectifiers in series would equal the voltage drop of 1 gaseous rectifier. Above this voltage the gas rectifier would tend to be more efficient, and below this voltage the solid state rectifier would be preferred, if this were the only criterion. To a first approximation, therefore, a gaseous discharge rectifier tends to be more efficient than a solid state rectifier in the high voltage field.

The losses in any auxiliary equipment, and in the heaters of hot cathode valves, must of course be included when determining the overall efficiency of a given rectifier circuit, and this will affect the critical peak inverse voltage at which one rectifier becomes more or less efficient than another.

The transformer connection can affect the overall efficiency of the rectifier circuit in various ways, particularly in the utilisation factor which is achieved. This is beyond the scope of the present article, but a complete treatment of this subject can be found in " Mercury Arc Rectifiers—Theory and Practice " by Marti and Winograd, and " The Fundamental Theory of Arc Convertors " by H. Rissik. As an example of the effect of transformer connection the case of a requirement for 4 kV d.c. output voltage may be considered. This might be met by using a biphase half-wave connection, in which the peak inverse voltage is about three times the output voltage. Here a 15 kV peak inverse rectifier would be working at its highest efficiency. If the same requirement were met using a three-phase full-wave rectifier connection, the peak inverse voltage required is very little more than 4 kV. A 15 kV rectifier would then be working at less than maximum efficiency and a different type of rectifier might be more appropriate.

Other secondary properties which are of importance include the ability of the rectifier to withstand overload current and inverse voltage surges ; the cost of the rectifier elements ; the life and reliability of the

rectifier ; the storage properties ; the ambient temperature over which the rectifier will function without damage to itself or to the rectifier circuit ; the cost of

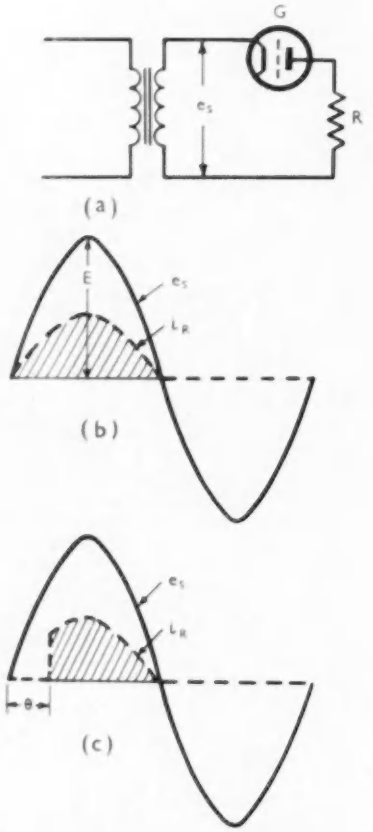


Fig. 1.—Single-phase grid-controlled rectifier.

any auxiliary equipment required ; the complexity, weight, size and ruggedness of the rectifier ; and the warming-up time.

The ability of the rectifier to be grid controlled can also be an important consideration in some applications. It has been stated that high voltage rectifiers are used to provide high tension supplies for vacuum oscillator valves. It is often desirable to vary the H.T. voltage in order to control the output power of these oscillators and, furthermore, some special types require a gradual application of the H.T. supply. This is frequently done by using a variable a.c. supply voltage, but this practice involves bulky and expensive regulators.

A more elegant method lies in the use of grid control. If the rectifier can be made with a grid electrode then the period of current flow through the rectifier can be controlled by varying the grid voltage and this, in turn, controls the d.c. output voltage. The exact method used will depend upon the particular rectifier which has been chosen but the associated equipment is usually quite small. The method is shown in essence in fig. 1, which is the simplest possible case of a single-phase grid-controlled unit with a resistance load, neglecting the arc drop of the rectifier. If the grid is struck at the beginning of the positive half cycle the mean output voltage is $\frac{E}{\pi}$ whereas if the firing is delayed by an angle θ the mean output voltage is $\frac{E}{2\pi}(1+\cos\theta)$. In a practical case the calculation will be more complex when multiphase rectification is used and the load contains smoothing inductance and capacitance in addition to resistance, but the principle is the same.

TYPES OF RECTIFIER.

The Hot Cathode Vacuum Rectifier.

The hot cathode vacuum valve was one of the earliest types of high voltage rectifier to be developed. The cathode usually consists of a tungsten, thoriated tungsten or oxide-coated filament. The electrons which are emitted form a negative space charge outside the cathode. As a result, a high anode voltage is required to draw the available cathode emission across the valve and the efficiency is therefore low when compared with gas filled valves, while the valve itself is very bulky. On the other hand, because of the absence of gas and with a relatively large spacing between cathode and anode, the maximum peak inverse voltage can be 50 kV or more. With a forward voltage drop of 1,000 volts the figure of merit is then about 50. Vacuum rectifier valves are suitable for a wide range of ambient temperatures ; they can be damaged if excessive overload is applied.

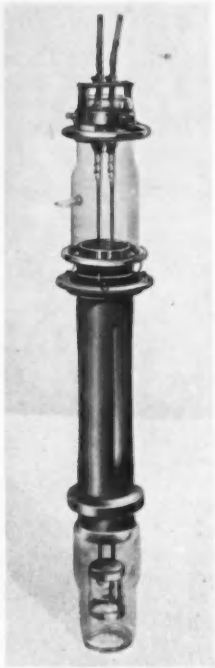


Fig. 2.—The CAR6 vacuum rectifier. Rating 50 kV peak inverse, 5 A mean current. The valve is approximately 3 ft. 6 in. long.

At peak inverse voltages up to 20 kV vacuum valves are used occasionally as power rectifiers. At higher voltages, for example in the power supplies of X-ray tubes, vacuum valves are the first choice. Fig. 2 shows a vacuum rectifier of the CAR6 type rated at 50 kV P.I.V. and 5 A mean current.

The Hot Cathode Gas-Filled Rectifier.

When a hot cathode rectifier is filled with a gas at

low pressure, the electrons which are accelerated across the valve collide with gas atoms, causing ionisation of the gas filling. The positive ions thus formed drift back towards the cathode, where they neutralise the negative space charge of electrons. As a result the whole available cathode emission can be drawn across the valve with an anode voltage little more than the ionisation potential of the gas concerned. The voltage drop is virtually independent of the anode current.

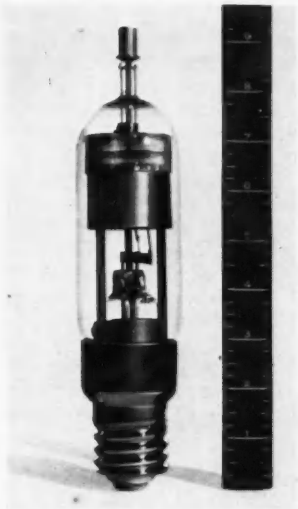


Fig. 3.—The GU23 mercury diode rectifier. Rating 20 kV peak inverse, 1·25 A mean current.

The gases most often used are mercury and xenon, both having a voltage drop of about 10-13 volts. The maximum peak inverse voltage, which is governed by Paschen's Law, can be as high as 20 kV for mercury, giving a figure of merit of 1,500. With xenon the maximum peak inverse voltage is about 13 kV, giving a figure of merit of 1,000.*

The cathodes of these rectifiers are usually of the oxide-coated type and the heater power required is about 10 watts per ampere of rectified current; therefore in calculating efficiency an equivalent 10 volts must be added to the actual voltage drop.

The life of a mercury valve can be 20,000 hours, limited by that of the cathode itself, if the valve is properly used. Care must be taken to ensure that the internal pressure, which is controlled by the condensation of mercury on the coldest part of the valve, is kept within fairly close limits. If no temperature control is used, the valve is suitable for ambient temperatures from about +10 deg. C. to +40 deg. C. To achieve the correct condensation temperature the valve must be warmed for several minutes before H.T. is applied. Mercury valves do not always store well; if they are kept unused for periods of two or three years the mercury may cause flaking of the cathode coating. A typical mercury diode rectifier, the GU23 rated at 20 kV P.I.V. and 1·25 A mean current, is shown in fig. 3.

If xenon filling is used the valve can be operated over an ambient temperature range from −55 deg. C. to +70 deg. C., and requires only 30 seconds switching delay. The valve can be stored indefinitely. Unfortunately xenon gas is cleaned up during operation and this limits the life, which is usually about 2,000 hours at full rating but may be as long as 10,000 hours at a reduced rating. Fig. 4 shows a recently developed xenon rectifier, the GXU5, which is rated at 10 kV P.I.V. and 4 A mean current.

Both mercury and xenon grid-controlled rectifiers have been developed. With mercury triodes the maximum peak inverse voltage is again about 20 kV and the mean current 3 A. Very high voltage xenon triode valves are not feasible at the present time since the rate of gas clean-up is so rapid in a rectifier circuit where high surge voltages are present at the instant of commutation. It is usual to limit a xenon grid controlled rectifier to a few kV peak inverse. Hot cathode grid-controlled rectifiers can be of the negative control type or the positive control type, depending upon the grid construction. With the former, the anode will conduct immediately the negative bias is removed and virtually no current flows in the grid circuit. With the latter a positive voltage must be applied to the grid, sufficient to form an auxiliary grid cathode arc, before the anode will strike. With either type the grid power involved is minute in comparison with the rectified load.

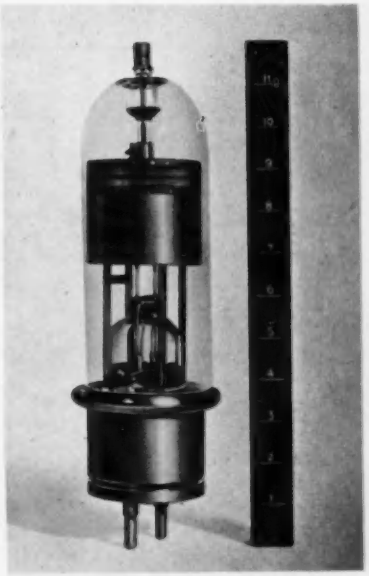


Fig. 4.—The GXU5 xenon diode rectifier. Rating 10 kV peak inverse, 4 A mean current.

* *G.E.C. Journal*, Vol. 24, pp. 110-113, April, 1957.

The Mercury Pool Rectifier.

The mercury pool rectifier is another gaseous discharge device and is similar in principle to the hot cathode mercury rectifier. It has a voltage drop only slightly higher than the ionisation potential of mercury and the peak inverse voltage can be as high as 25 kV, giving a figure of merit of 1,800. The cathode consists of a mercury pool over the surface of which the cathode spot wanders. No cathode heater power is required and the cathode is continuously replenished as recondensed mercury falls back into the pool. The life can therefore be extremely long. The cathode is capable of sustaining high overcurrents without damage but, on the other hand, the valve is susceptible to ambient temperature variations. Furthermore, the swilling of the mercury can cause trouble if the valve is moved while operating. The cathode spot will extinguish itself if the anode current falls below about 3 A, or at a lower limit if a " spot fixer " is used. A holding electrode is commonly used to maintain a continuous cathode spot regardless of the load on the main anode. Naturally, this increases the complexity of the equipment and results in a power loss which slightly reduces the overall efficiency.

Mercury pool rectifiers, which may be of the single anode or multi-anode type, can be grid-controlled and the grid power required is again quite small. Fig. 5 shows a power supply using excitron grid-controlled mercury pool rectifiers. The rectifiers are rated at 16 kV P.I.V. and 5·6 A mean current. Valves of this type are finding increasing favour in static high power equipments for 100 kW or more where the additional equipment required for the holding electrode is no embarrassment.

Solid State Rectifiers.

Until recently, the selenium rectifier was the only solid state rectifier of importance in the high voltage field. The forward voltage drop in selenium is about 1·5 volts* and the maximum peak inverse voltage of each element is about 40 volts. The figure of merit is therefore in the region of 30. In spite of this low value, selenium rectifiers have been used for high voltages, a large number of elements being connected in series to give the required peak inverse voltage. The current is usually quite low, although circuits giving currents of 8 A at 6 kV output voltage have been constructed. These are, however, quite bulky. The advantage of selenium lies in the elimination of any form of heater transformer or control apparatus and in the robustness and reliability of the device. The life can be very long compared with hot cathode valves and no switching delay is required before H.T. can be applied.

The outlook is now changing with the introduction of the newer types of semiconductor rectifier, particularly the silicon type. These rectifiers have a figure of

* B.S. 2709 : 1956, Clause 6 (c).

TABLE 1.

	Hot Cathode Vacuum	Hot Cathode Mercury	Hot Cathode Xenon	Mercury Pool	Selenium	Silicon
Figure of Merit	50-100	700-1,400	1,000	2,000	30	200-400
Current Overload Capacity	Low	High	High	Very High	High	Low
Life (hours)	5,000-20,000	10,000-20,000	2,000-10,000	Greater than 20,000	Greater than 20,000	Greater than 20,000
Reliability	Good	Good	Good	Good	Very Good	Very Good
Warming-up Time	30 seconds	About 10 minutes	30 seconds	Nil	Nil	Nil
Possibility of Grid Control	Difficult	Yes	Yes	Yes	No	No
Storage Properties	Good	Cathode flaking may give trouble	Good	Good	Good	Good
Ambient Temp. Range ...	Very Wide	Narrow	Very Wide	Narrow	Wide	Very Wide
Robustness	Good	Good	Good	Mercury swill might give trouble	Very Good	Very Good
Size (of complete rectifier unit)	Large	Very Small	Very Small	Very Small	Large	Small
Auxiliary Equipment ...	Heater transformer	Heater transformer	Heater transformer	Exciting current supply required	Nil	Nil

merit of about 400 at the present time and it is thought that this may soon be increased. Silicon rectifiers work over a wide range of ambient temperature and, as with selenium, no heater transformer or control apparatus is required. The life is, again, potentially very long. It is possible that silicon rectifiers may compete with gas discharge devices in the near future in the high voltage field, though this conclusion is to some extent modified by the fact that grid-controlled solid state rectifiers are not yet a practical possibility and also that, unlike gas discharge devices, they will not tolerate heavy overload currents.

CONCLUSION.

This survey has described various types of rectifier, each with its own advantages and disadvantages. Table 1 summarises briefly the important secondary properties of these rectifiers. In some applications it is easy to select the best rectifier, but often the user will find that several types are almost equally suitable. In these circumstances, a marginal improvement in the performance of a particular type may become all-important. A small reduction in voltage drop, a slight increase in peak inverse voltage or a small reduction in size may well determine which type of rectifier is preferred.

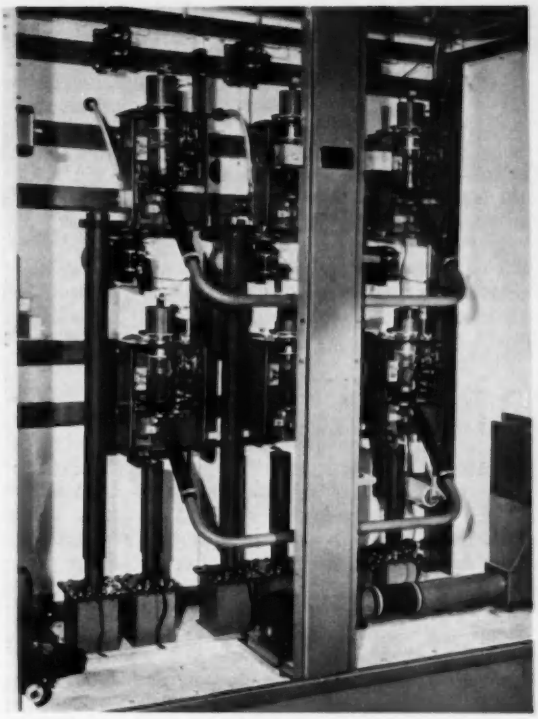


Fig. 5.—A power supply using 6 excitron grid-controlled mercury pool rectifiers. The cubicle is 7 ft. high.

GENERATING PLANT FOR MINES

A G.E.C. 1,750 kW, 3·3 kV, 218 r.p.m. alternator driven by a Crossley Premier 16-cylinder horizontal vis-à-vis engine in the power house of Lake View & Star Ltd., Finniston, Western Australia.

Three-phase A.C. Distribution for Ships' Auxiliaries

By W. R. COX, B.E. (Elec.) N.Z., A.M.I.E.E.,
Witton Engineering Works.

MANY papers have been written which deal mainly with the generator and motor side of three-phase a.c. electrification for ships' auxiliaries. This article is concerned with the distribution system and the necessary switch and protective gear. The discussion is confined to ships of the Merchant Navy—warships of all types are essentially fighting machines, where the first consideration is the maintenance of fighting power and efficiency when the ship is damaged to a greater or less degree. This factor introduces problems which do not seriously affect the design of merchant ships and eventually leads to conclusions which are considerably different in the two cases.

Up to the present time nearly all ships' a.c. supply systems have been designed to operate with an insulated neutral, but a case is made here for use of an earthed neutral, which is almost universal British practice for a.c. distribution systems in any other situation. In the author's opinion a system with an earthed neutral is both safer and easier to maintain and serious consideration should be given to the adoption of such systems.

The types of ship mainly in mind are cargo and passenger-cargo vessels from 3,000 to 20,000 tons, and passenger ships from 8,000 to 30,000 tons. What might be termed special-purpose ships such as trawlers, tugs, dredgers and short-distance passenger ships have not been given detailed consideration, but many of the problems are common to all types.

AUXILIARY LOADS.

The auxiliary loads on a ship generally fall into two classes :

(*a*) *Essential loads* associated with the safe and efficient handling of the ship.

(*b*) *Non-essential loads* associated with the comfort and well-being of passengers and crew, but which can be cut off temporarily without danger.

Sometimes the non-essential loads are divided into two groups of greater and lesser importance. At times of fault or other difficulty the less essential load is automatically tripped out in order to maintain essential supplies.

Finally, the essential auxiliaries are either duplicated or provided with ample standby plant which can be quickly brought into operation when necessary.

DISTRIBUTION SYSTEM.

The distribution system layout must be very flexible so that the features mentioned in the preceding paragraphs can be preserved under all possible fault conditions.

Most of the essential load is concentrated in the engine room, but certain items, such as the steering gear, navigation lights, certain deck machinery and sufficient lighting throughout the ship to allow efficient operation, represent loads at some distance from the engine room.

The non-essential loads are distributed in a similar manner but a greater proportion of this load is remote from the engine room.

Individual motor starters can be situated near their motors, but a neater arrangement is obtained if as many starters as possible are incorporated in group starter boards, fed from the main switchboard, or in some cases in the main switchboard itself. This arrangement contributes to the efficient running of the ship in that the engineers can control and supervise most auxiliaries from a few centrally placed switchboard instead of having to go to starters placed near the various motors.

Bearing the above features in mind, together with the need for maximum flexibility, a distribution system generally laid out as shown in fig. 1 provides the best arrangement.

The main switchboard busbars are divided into two nearly equal parts joined by a bus coupler circuit breaker. Half the generators are connected to each side of the bus coupler.

The important motors are in duplicate, one being fed from each side of the bus coupler. In the same way, the less important motors, lighting, heating and cooking loads are distributed so that each side of the bus coupler is nearly equally loaded.

It is generally good policy to take only the larger loads from the main switchboard.

A method of giving a very high degree of standby for group starter boards is to divide the boards at each remote load centre into two parts, supplying each part from one side of the main busbars by a cable of large

enough capacity to take the whole load at the remote load centre ; and to provide changeover isolators so that the boards can either be supplied separately, one on each cable, or both boards can be supplied in parallel on either cable.

Normally the bus coupler is closed and all alternators are operated in parallel, but the above arrangement gives very good flexibility for maintaining supplies, particularly to essential services, during periods immediately following almost any type of fault.

Motor Starters.

As many motors as possible should be of the squirrel cage type with D.T.L. starters. This allows the use of the simplest and most robust type of motor and starter, but the starting current is relatively high, generally between five and ten times full load current. This is no inconvenience for the smaller motors, but some of the motors are large compared with the alternator output and a point is reached when a partially loaded alternator will not deal with this additional starting current without disturbing the system to an unacceptable degree. The larger motors must therefore be of the wound-rotor type with rotor starting resistances ; alternatively auto-transformer starting or star/delta starting can be used in some cases.

VOLTAGE.

A three-phase system must be used in order to obtain any advantage from the use of a.c., and the first question needing serious consideration is the voltage or voltages to be used.

With d.c. the voltage commonly adopted is 220 volts, with a 2-wire, all-insulated system. Generally speaking a 3-phase system at about 400 volts between phases is suitable. A higher generator voltage such as 3·3 kV has been advocated, but unless a considerable proportion of the power can be used at the higher voltage, any saving in the alternators and distribution cables would be more than offset by the cost of the additional transformers necessary.

Unless the auxiliary alternator capacity exceeds

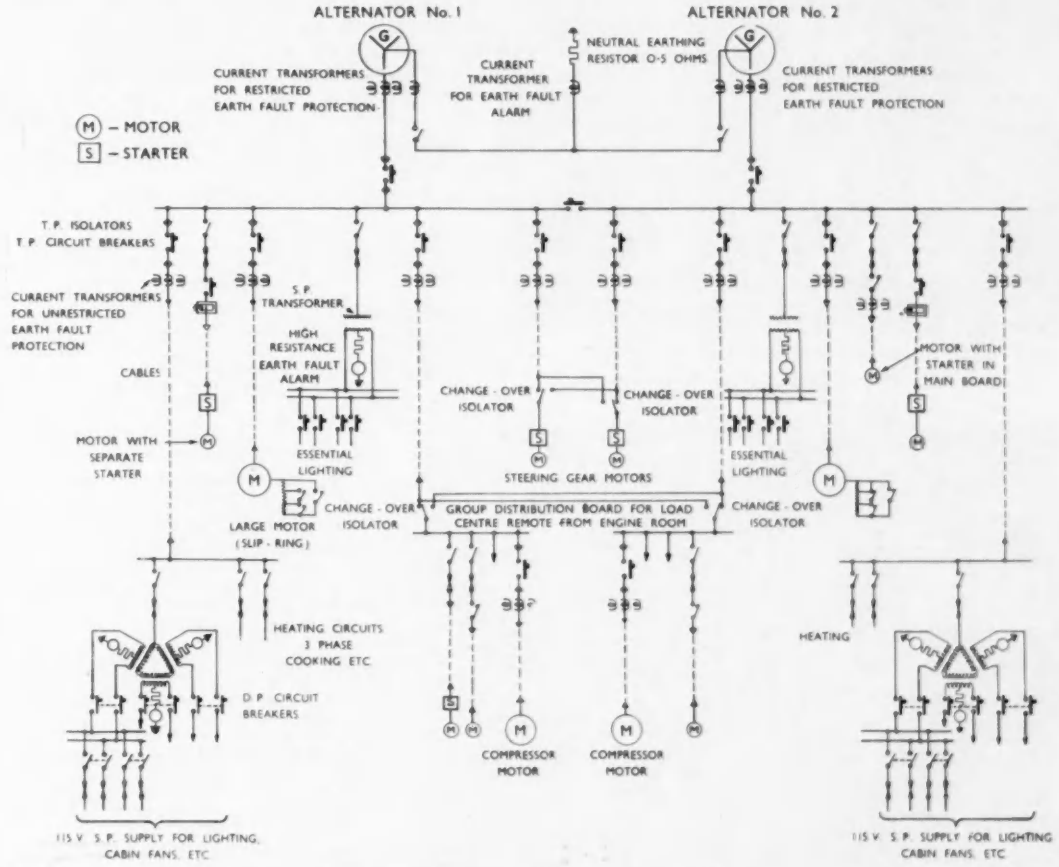


Fig. 1.—Typical a.c. distribution system for ship.

3,000 kW, generation at the lower voltage is recommended.

If the neutral of the three-phase system is solidly earthed or earthed through a relatively low resistance, the voltage to earth does not exceed 230 volts. At first sight it would seem possible to supply lighting circuits and other single-phase apparatus direct from such a system in the same way as has been adopted in the 2-wire d.c. system. There are, however, several points of difference :

(1) Since the neutral is earthed, there is always 230 volts between the live wire and earth. In the case of the 220 volt d.c. system with both lines insulated from earth, there is only 220 volts between one line and earth when there is a fault somewhere on the system. At other times the voltage would only be approximately 110 volts and, furthermore, the accidental earthing of a live line would not cause a large fault current to flow to earth.

(2) The risk of shock is greater in a ship than on land as the frame of the ship constitutes an unusually good earth return path for fault currents and in general " earth free " situations do not occur. On the other hand, if the neutral of the 400 volt system is insulated, there is always a possibility of there being 400 volts to earth from any line and the dangers referred to above are accentuated.

The above considerations indicate that the lighting circuits and many of the domestic services should be fed through transformers and run at, say, 115 volts between phases.

TREATMENT OF NEUTRAL.

It is not always appreciated that the method of treating the neutral of any three-phase system has a profound effect on the design of the distribution system. A decision on this point is of first importance and immediately leads to limitations in the layout of the distribution network, the protective equipment to be used, and even the type of plant and apparatus which can be used.

The choice available is very wide. At one extreme, the neutral may be solidly earthed, and at the other it can be fully insulated. Between these two limits there

TABLE 1.

	Solidly-Earthed Neutral	Fully-Insulated Neutral
Potential ..	The voltage to earth from any point of the system is always $\frac{\text{line voltage.}}{\sqrt{3}}$ During switching, faults and other disturbances there is little likelihood of transient high voltages appearing on the system. Danger to personnel from shock is a minimum for the system line voltage in use.	The voltage to earth from any point of the system is somewhat indefinite. According to the state of the insulation it may vary between line voltage and $\frac{\text{line voltage.}}{\sqrt{3}}$ Danger to personnel from shock is greater than with the earthed neutral.
Fault Currents	Upon the occurrence of an earth fault a heavy fault current flows. This makes the automatic isolation of the faulty circuit comparatively easy. When an earth fault occurs the faulty circuit must be quickly isolated.	Upon the occurrence of *one* earth fault, the earth fault current is limited to the capacity current between the system and earth—which will be small in the case of a ship's distribution system at, say, 400 volts, but may be large enough to maintain an arcing earth which constitutes a fire risk. It is very difficult to isolate such a fault automatically. Should a second earth on another phase occur, before the first has been cleared, a phase-to-phase fault is created entailing very heavy fault currents and probably considerable damage to *two* pieces of apparatus.
Insulation ..	Insulation on all apparatus, machine windings, etc., can be suitable for $\frac{\text{line voltage}}{\sqrt{3}}$ to earth. *N.B.*—For mechanical reasons the insulation on machine windings is usually very ample on the lower voltage machines (up to 500 V) but this does not apply to many other pieces of apparatus, such as thermostats, resistance regulators, switches, etc.	Insulation on all apparatus, machine windings, cables, etc., must be suitable for line voltage to earth. *N.B.*—This rules out the use of many highly developed and readily available pieces of apparatus such as tumbler switches, thermostats, lamp fittings, etc. A second earth fault causes a phase-to-phase fault and the likelihood of very high fault currents.
Maintenance	Earth faults (which must be automatically isolated) are readily located.	The presence of an earth fault somewhere on the system is easily detected, but its location is difficult. This introduces a tendency to run with a fault on the system and if a second fault should develop during this period the risk of fire and damage is considerably increased.

is an infinite variety in the choice of impedance which may be introduced between the neutral and earth.

Other variations may be introduced by considering where the neutral is to be connected to earth and whether it should be connected in more than one place. In an endeavour to simplify the variations, a table has been prepared comparing some of the characteristics of a solidly earthed neutral with a fully insulated neutral. It is assumed that the earthing is carried out at generator neutrals and the neutrals of the secondaries of supply transformers.

Table 1 sets out the two extremes of the variations available. The next step is to examine the good and bad points of each to see whether the introduction of some impedance in the neutral/earth connection can give a compromise which is better than either of the two extremes.

The outstanding merits of the earthed neutral are :

(*i*) The voltage to earth is limited to phase voltage or $\frac{1}{\sqrt{3}}$ of line voltage.

(*ii*) An earth fault can be readily located and automatically isolated.

The predominant undesirable feature is the possibility of heavy earth fault currents, making the automatic isolation of earth faults essential.

The outstanding features of a fully-insulated neutral are :

(*i*) The limitation of the current to earth on the occurrence of one fault to the capacity current. The value of this current will vary from installation to installation, but is likely to be of the order of 1 amp.

(*ii*) The voltage stresses on insulation are much more indefinite and are generally higher than with the earthed neutral.

(*iii*) Shock hazard to personnel is greater.

(*iv*) While an earth fault can be detected, it is difficult to locate.

An arcing earth of the order of 1 amp, if left for any time, can constitute a fire risk and in the case of tankers would cause a considerable risk of explosion if the fault occurred in the vicinity of any pocket of explosive vapour.

As indicated earlier, these conditions can be varied by the introduction of an impedance between the generator neutral and earth. This impedance

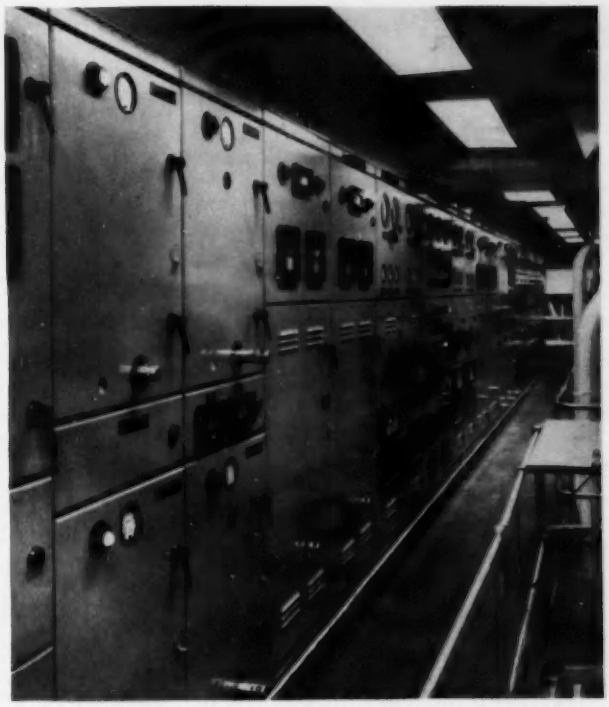


Fig. 2.—Main a.c. air-break switchboard in the M.V. "Bergensfjord".

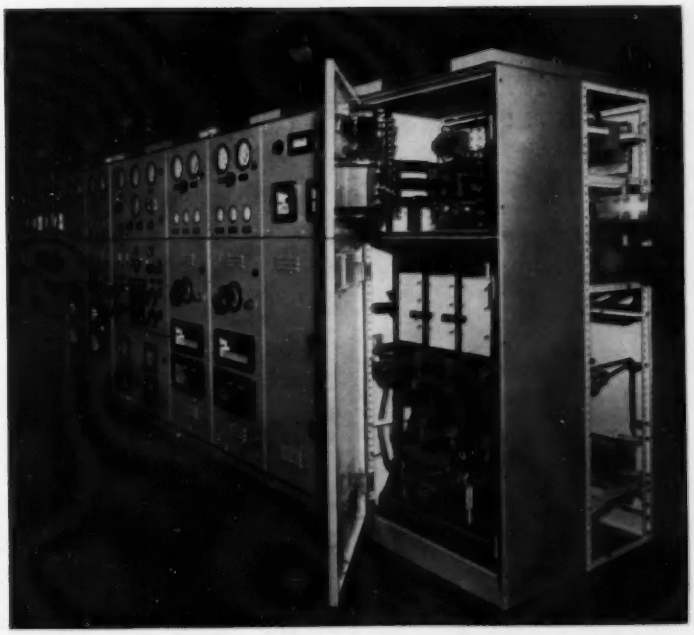


Fig. 3.—Alternator section of the main switchboard for the M.V. "Bergensfjord".

may take the form of :

A non-inductive resistance.

A reactance.

A tuned reactance (Peterson coil).

Non-Inductive Resistance.

The introduction of a resistance between the neutral and earth limits the amount of damage and system disturbance resulting from an earth fault and at the same time provides enough fault current to ensure discriminative earth fault protection.

Fig. 4.—Group starter board for an oil tanker.

A resistance of 0·5 ohm in the generator neutral of a 400 volt, 3-phase system will limit the maximum possible earth fault current to 460 amp, which gives ample scope for the quick and certain action of an earth fault relay, with a setting of, say, 40 amp. Such a relay on a 300 amp (full load) feeder will be robust and easily maintained. A similar relay on, say, a 100 amp feeder would have a setting of, perhaps, 15 amp. If the resistor were 0·25 ohm the maximum earth fault current rises to 920 amp and sensitivity of relays remains.

A resistor of 1·0 ohm reduces the maximum earth fault current to 230 amp.

The above possible earth fault currents are maximum figures and are by no means the magnitude of most faults. For this reason the maximum possible fault current must be kept relatively high so that the protective gear is given a chance of quick and certain operation. The suggested resistance is therefore 0·5 ohm.

The fire danger caused by an earth failure is partly a function of current and partly a function of time ; a moderate current for a short time is probably less dangerous than a small current for a long time.

Reactance and Tuned Reactance.

As an alternative to resistance earthing for a L.V. system, neither a fixed reactance nor a tuned reactance gives any technical advantage. Both are used on H.V. systems, particularly when they prove to be more economical in cost and space. This does not usually apply for L.V. systems.

Before making a definite recommendation it is interesting to review briefly the land practices which have been developed for L.V. systems over the last 30 years or so. American practice has been to adopt an insulated neutral, which is still largely used, while British practice is almost universally to use an earthed neutral, with limitation of magnitude of the possible earth fault current to somewhere about the full load of the largest generator on the system.

It is, however, of interest to note from several articles recently published in America that there is a tendency there to go over to earthed neutrals.

From a review of the wide choice of alternatives, the author's recommendation is to earth the neutral through a resistance of 0·5 ohm, which, in conjunction with properly designed earth fault protection, will give the safest possible installation.

Switchgear.

The general form of the switchgear should be metal-enclosed, air-insulated cubicles. This type of gear, illustrated in fig. 2, 3 and 4, had been developed for use on board ship and gives a neat and safe arrangement. It is important that the various circuits should be segregated internally and arranged for safe and ready maintenance while adjacent circuits are in operation.

The design is so arranged that a large variety of equipment such as main circuit breakers, contactor starters, switch fuses, and so on can be accommodated in similar cubicles or sections of cubicles, enabling the various circuits on the switchboard to be arranged to the best advantage from an operating point of view, while at the same time maintaining a neat appearance and a compact switchboard.

Breaking Capacity.

On an a.c. system the maximum severity of a short circuit is readily estimated with a fair degree of accuracy and current breaking devices are designed and tested for various breaking duties.

In the cases under review the only source of fault current is the alternators and the average reactance of such machines is 12½ per cent. The breaking capacity necessary for various sizes of installation can therefore be tabulated as shown in Table 2.

Air break circuit breakers available for 25 and 15 MVA breaking capacity, fig. 5 and 6, are rather bulky and at the moment there does not seem to be much

TABLE 2.

Total generator capacity (assuming all in parallel)	Breaking capacity
3,000 kW	25 MVA (36,000 amp)
2,000 kW	15 MVA (21,750 amp)
1,250 kW	10 MVA (14,500 amp)
1,000 kW	8 MVA (11,600 amp)
625 kW	5 MVA (7,300 amp)

hope of materially reducing their size, while still maintaining the necessary breaking capacity.

In the 8 and 10 MVA range, the panel-mounted type of breaker (similar to those largely used for d.c.) is a good deal more compact and can readily be mounted in the standard size and shape of cubicle. In this case space can be saved by tiering the breakers, two, three or four per cubicle.

For smaller ships with not more than 625 kW installed capacity of alternators, a range of miniature circuit breakers is available which have carrying capacities up to 50 amp and breaking capacity up to 5 MVA. These breakers are very useful for the smaller circuits, and in any ship can be extensively used for lighting circuits, where, due to the interposing of a transformer between the main busbars and lighting busbars, the short circuit capacity on the latter bars is nearly always less than 5 MVA.

Main circuits fed from the busbars must all be equipped with fully rated circuit breakers, but there are always a number of smaller circuits fed from the same busbars where the size and cost of a circuit breaker is not economical. In such cases switch fuses can be satisfactorily used to give a compact arrangement at low cost, provided H.R.C. fuses of ample breaking capacity are fitted.

Fuses introduce a number of disadvantages, the chief of which are :

(*i*) Possibility of single phasing due to failure of one fuse.
(*ii*) Loss of time in replacing fuses.
(*iii*) Inability to protect reliably between 100 per cent and 200 per cent of normal load.
(*iv*) Need to carry a good stock of spare cartridges and inability to improvise if the stock is used up.

Note : Rewiring over the outside of the cartridge is a *highly dangerous practice* and must never be allowed.

The first and third disadvantages can be overcome by the use of a circuit breaker or contactor of lower breaking capacity, backed up by fuses, which can then be rated up to deal with short circuits only.

Fuses of the lower capacities can be used for earth fault protection as well as for overcurrent protection on these circuits. This feature is explained more fully under the section on protection.

To use successfully a circuit breaker or contactor of relatively low breaking capacity backed up by fuses,

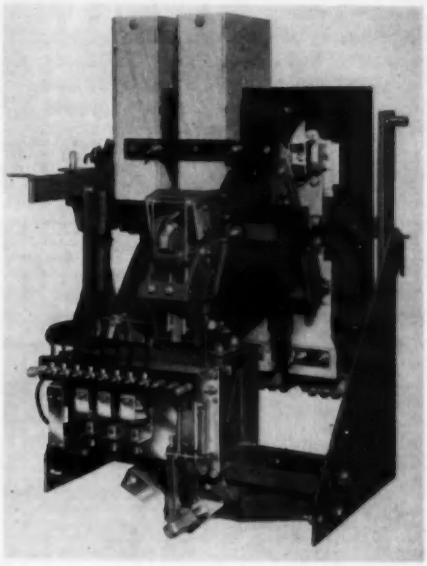


Fig. 5.—800 amp hand-operated air circuit breaker with one arc chute removed.

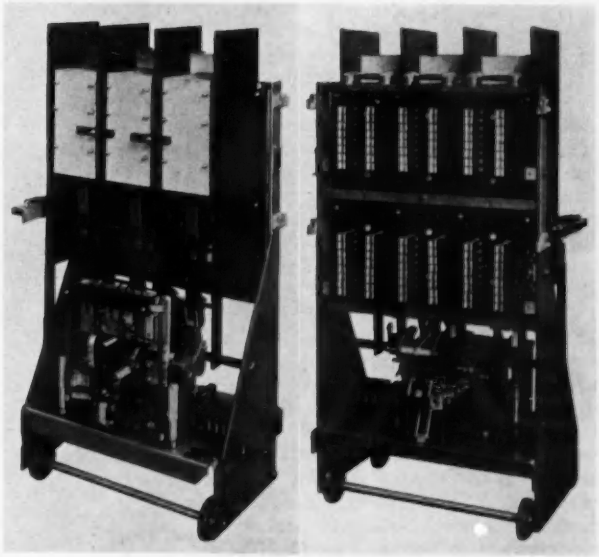


Fig. 6.—Front and rear views of a 2,000 amp air-break circuit breaker.

the associated overcurrent device must be of the inverse time delayed pattern and co-ordinated with the fuse characteristics in such a way that if the fault is beyond the breaking capacity of the circuit breaker or contactor, the fuses will blow before the breaker or contactor opens.

As an illustration (see fig. 7) the case has been taken of a squirrel cage motor with full load current of 30 amp, standstill current 150 amp, and the limiting safe breaking capacity of the contactor at 240 amp.

The curves *A* and *B* show the current/time characteristics of two types of overcurrent relay ; and curves *C*, *D* and *E* the current/time characteristics of three different sizes of H.R.C. fuse.

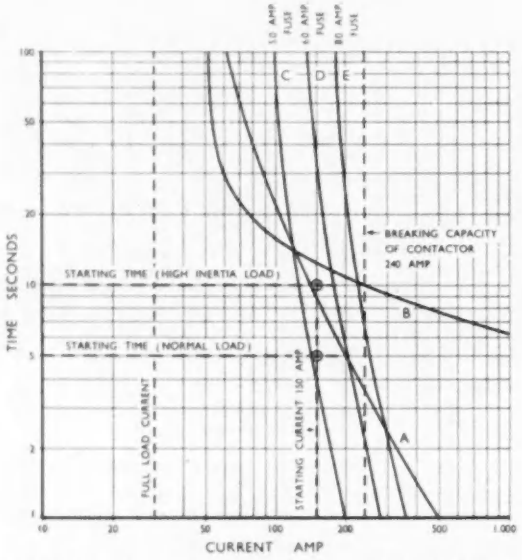


Fig. 7.—Co-ordination of overcurrent relays and H.R.C. fuses for protection of motor circuits.

Now if the motor and its load are such that the motor will accelerate to full speed in 5 seconds, the overcurrent relay to curve *A* is quite suitable as this will not trip on standstill current for 9 seconds. Looking now at the fuse curves, curve *C* for a 50 amp fuse indicates that the standstill current for 4 seconds would blow the fuse. While such a fuse probably would not blow every time the motor is started, it would be sure to " age " and the fuse is not suitable for this application. The 60 amp fuse whose characteristic is shown on curve *D* is the correct fuse for this application. The fusing time on standstill current is 30 seconds and at fault currents in excess of about 200 amp (where curves *A* and *D* cross) the fuses will operate faster than the contactor. This ensures that the contactor will always operate well within its breaking capacity. The 80 amp fuse (curve *E*) is also unsatisfactory in that for fault currents up to 270 amp, i.e. somewhat above the breaking capacity of the contactor, the contactor will open before the fuses blow.

Assume now that we have the same motor and starter but a high inertia load, which prolongs the starting period from 5 to 10 seconds. It is seen that the overcurrent relay with characteristics to curve *A* will be unsuitable as there will be a risk of this tripping before a normal start is completed. In such a case an overcurrent relay with characteristics as shown on curve *B* should be selected. It should also be noted that the 60 amp fuse is too light and the 80 amp fuse is recommended in this case. Due to the changed shape of the relay characteristic, heavy current faults will always be cleared by the fuses if the currents are too heavy for the contactor.

PROTECTION.

Having laid out the distribution system in detail, a careful review of the whole plant must be carried out from a protective point of view, to evolve comprehensive protection against both earth faults and overcurrents.

The protective system must achieve the following results on the plant as a whole :

(*i*) All protective devices must be stable under all normal load conditions.

(*ii*) A faulty piece of apparatus must be disconnected with, if possible, no disturbance to healthy apparatus.

(*iii*) Leakage to earth which can be maintained for a sufficient time to cause a fire hazard, must cause the faulty circuit to be tripped.

(*iv*) All protective devices must operate correctly with a single alternator running or with any number of the installed alternators operating in parallel.

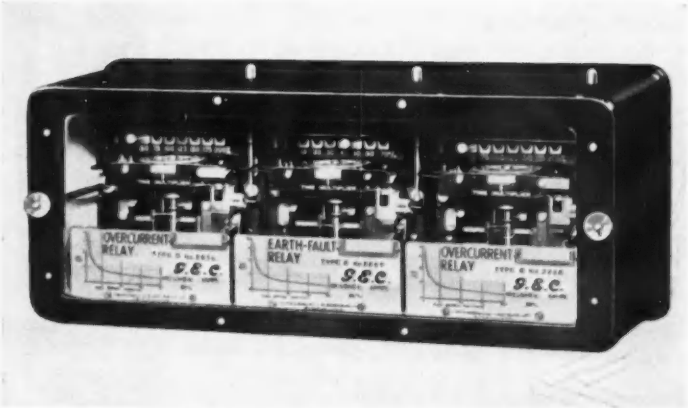


Fig. 8.—A typical triple-pole overcurrent and earth fault relay.

Fig. 9.—Standard 3-element biased differential relay.

(*v*) Back-up earth fault protection to be established and preferably worked in with a scheme of preferential tripping of the less essential loads to ensure continuity of essential supplies whenever possible.

(*vi*) Back-up overcurrent protection on each alternator is also required to guard against the possible overloading of the generators running at any particular time, by disconnecting some of the less essential load.

Discriminative tripping inferred from the above can in general be obtained in two ways :

(1) A differential protective scheme, which is inherently stable to through faults and which can therefore trip instantaneously upon the occurrence of a fault within the zone covered by the protection.

(2) Current and time grading for both the overcurrent and the earth leakage protective devices.

Both types of scheme are used.

To implement the above broad principles it is found necessary to divide circuits into various categories based partly on the size of load and partly on the relative importance each circuit assumes in the safe and efficient running of the ship. Each class of circuit is then equipped so that the whole system of protection is co-ordinated from the alternators to the motor, lighting or heating circuit control switches in such a way that a fault at any point will trip only the next automatic isolating device towards the power supply. Thus wherever the fault may be, a minimum of plant is shut down as a result of that fault.

In order to examine these arrangements in greater detail the case of the M.V. " Bergensfjord " has been taken as an example. This is a passenger ship of 18,739 tons register of the Norwegian America Line. There are four auxiliary generators, each of 1,300 kVA, driven by diesel engines and the load is such that there will not be more than three running at any one time.

Power is generated at 440 volts, 3-phase, with the neutral earthed at an alternator through a 0·5 ohm resistor. All the distribution is 3-wire, no load being supplied between one phase and neutral.

The alternators feed on to the single set of busbars in the main switchboard and the majority of the load is supplied direct from this switchboard. There are, however, four group starter boards, namely :

Engine Room Port Group Starter Board.

Engine Room Starboard Group Starter Board.

Oil Fuel Services Group Starter Board.

Stabiliser Group Starter Board.

A single-line diagram of the " Bergensfjord " system is given in fig. 11, in which only representative circuits are shown. In all cases there are at least two and frequently more circuit interrupting devices between the alternators and the loads.

Overcurrent Protection.

Taking the case of a scavenger blower motor and an alternator :

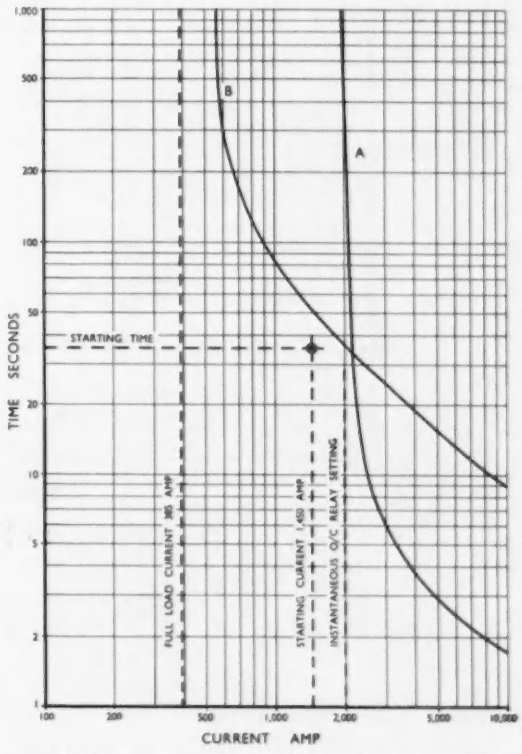


Fig. 10.—Overcurrent protection curves for scavenger blower motors.

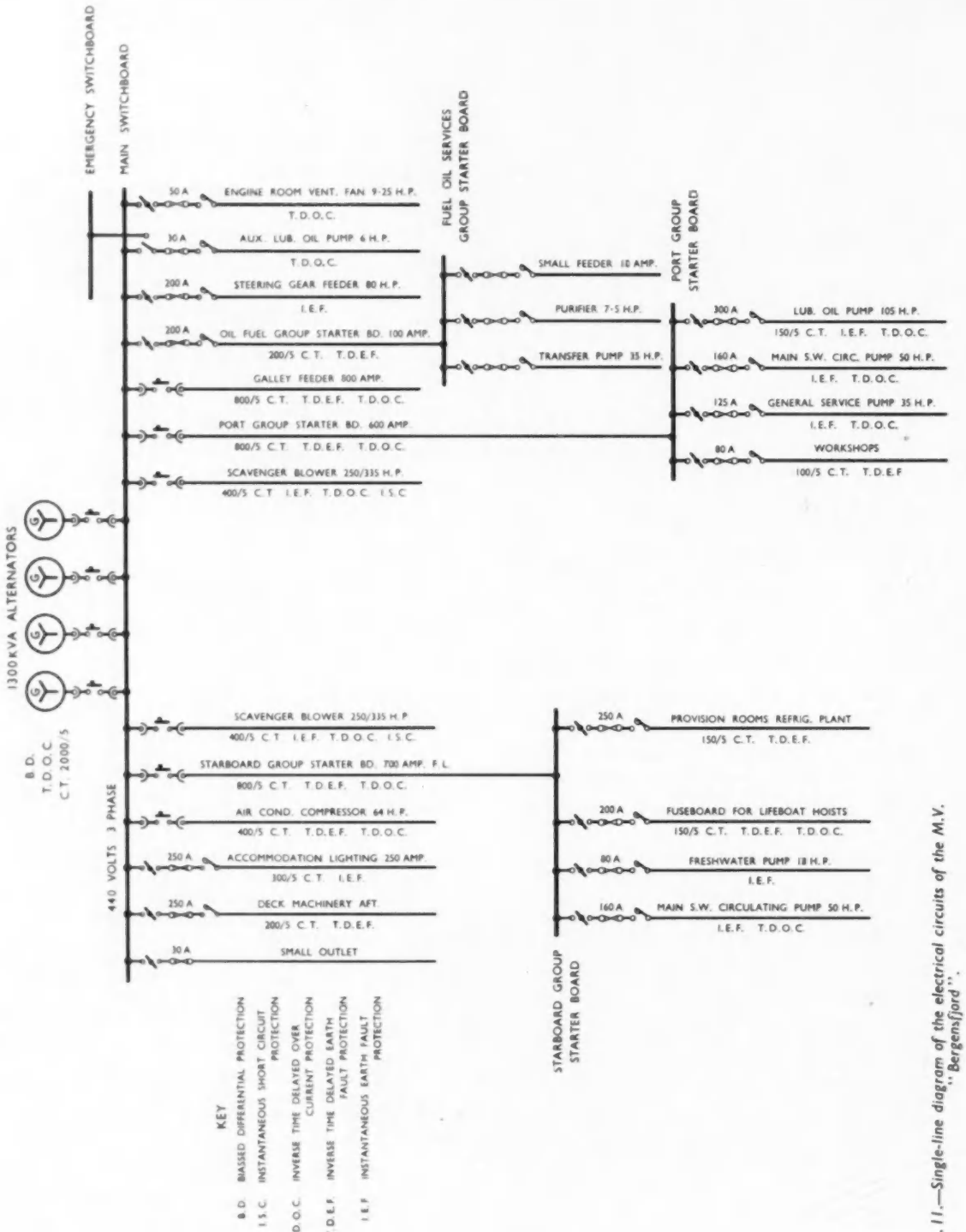


Fig. 11.—Single-line diagram of the electrical circuits of the M.V. "Bergensfjord".

The alternator full load is 1,700 amp.
Current transformer ratio 2,000/5 amp.
Relay current setting 100 per cent.
Relay time setting 0·4 time multiplier.
The relay characteristic for the above settings is shown on curve *A*, fig. 10.
The scavenger blower motor is 335 h.p., two-speed—
Full load current 385 amp.
Starting current 1,450 amp.
Running up time 35 sec.
Current transformer ratio 400/5 amp.
Saturable core overcurrent trip with dashpot time delay, the characteristic of which is shown on curve *B*, fig. 10 :
Setting 125 per cent.
Instantaneous O/C setting 2,000 amp.
From an examination of fig. 10 it will be seen that :

(1) No relay will operate with the starting load of 1,450 amp within the 35 seconds required for starting the scavenger blower.
(2) Upon the occurrence of an overcurrent in the motor of any value up to the maximum output from 1, 2 or 3 alternators, the motor relay will operate quite certainly before any of the alternator relays operate.

As a second example, take the case of a lubricating oil pump motor. The motor control gear is on the port group starter panel and we therefore have three current interrupting devices in series, which for an overcurrent on the motor must trip in the correct sequence.
The alternator details are as before.
The group starter feeder circuit breaker is protected by an induction pattern overcurrent relay :
Relay current setting 150 per cent.
Relay time setting 0·15 time multiplier.
Current transformer ratio 800/5 amp.
The relay characteristics for the above settings are shown on curve *B*, fig. 12, while curve *A* shows the alternator relay characteristics.
The lubricating oil pump motor is 105 h.p.
Full load current 120 amp.
Starting current 750 amp.
Starting time 10 sec.
Current transformer 150/5 amp.
Overcurrent protection by saturable core overcurrent relay setting 125 per cent backed up by 300 amp H.R.C. fuses.
The overcurrent relay is arranged to trip the contactor, which has a maximum breaking capacity of 1,200 amp. The relay characteristic is shown on curve *D* and fuse characteristic on curve *C*, fig. 12.
From fig. 12 it will be seen that :

(1) There is an ample margin between the normal starting time and the tripping time for the motor relay when subjected to starting current.

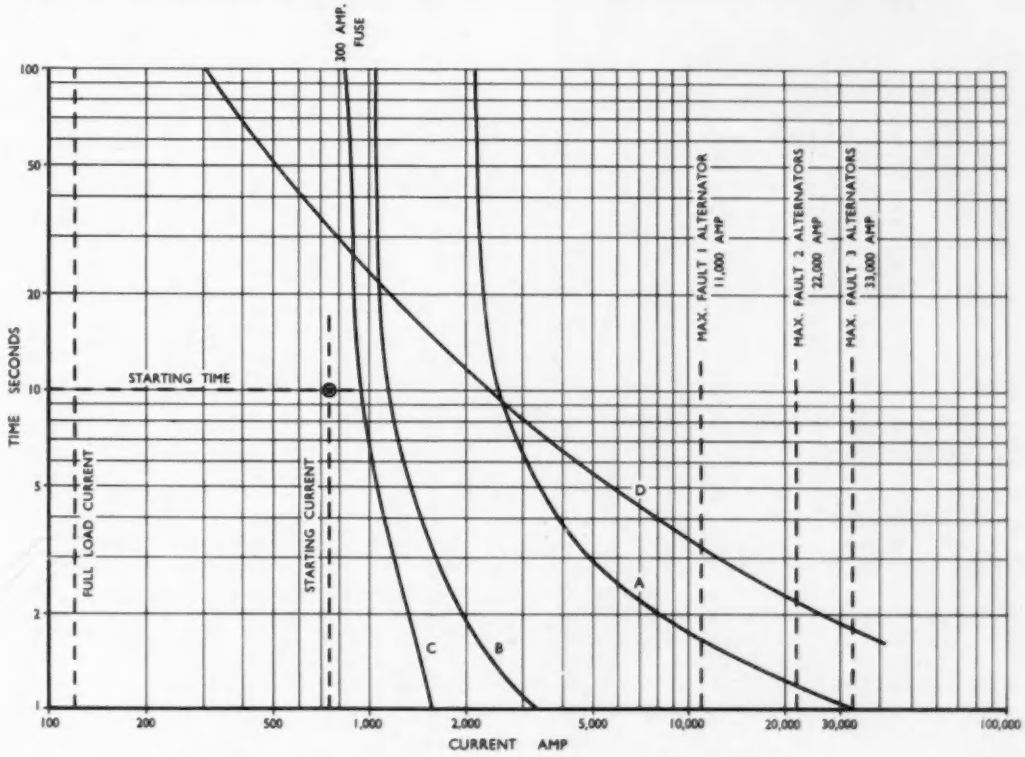


Fig. 12.—Overcurrent protection curves for lubricating oil pump motors.

(2) The back-up fuses will blow before the relay operates at a current of 1,000 amp, which is within the breaking capacity of the contactor.
(3) Under all overcurrent conditions the motor circuit will open before the group feeder is tripped.
(4) In event of a cable fault on the feeder to the group starter board, the group feeder breaker will trip before the alternator breaker.

Back-up Overload Protection.

A further overload feature provided on the alternator circuits is designed chiefly to guard against the inadvertent overloading of an alternator to such an extent that it may cause the diesel engine to stall.

This consists of a single-pole over-power relay fitted to each alternator, connected to operate two timing relays which in turn operate on two stages of preferential tripping so that the less essential loads are tripped off in two stages in order to reduce the total load on the engines without impairing the safe operation of the ship.

Earth Fault Protection.

The majority of faults which occur will be initially earth faults so that all circuits must be protected for such faults and, further, the earth fault protection must discriminate in a similar manner to the overcurrent protection. The rapid isolation of any faulty apparatus at a low value of fault current not only minimises the disturbance to the ship's supply generally, but results in minimum damage to the faulty apparatus.

In order to avoid excessive earth fault current flowing, an earthing resistor is connected between the alternator neutral and earth, i.e. the hull of the ship. This resistor limits the earth fault current to a maximum of approximately 500 amp.

The overall earth fault protection is arranged in three stages. The first stage, which protects the load-consuming apparatus itself, is in general instantaneous in operation. For the lower current circuits the fuses which normally protect against short circuits also give satisfactory earth fault protection. In this case, however, the operation is not instantaneous.

The second stage, which protects the connections between the source of supply and the load, is by relays of the induction type with inverse time characteristics. These are set for a slight time delay to obtain discriminative tripping with either relays or fuses which are farther away from the source of supply.

Where there are several of these relays in series between the source of supply and the load, their operating times are adjusted so that the relays nearer the source of supply have longer operating times.

The third stage, which is the last line of defence, and which should seldom, if ever, be called upon to operate, consists of relays with a much longer time of

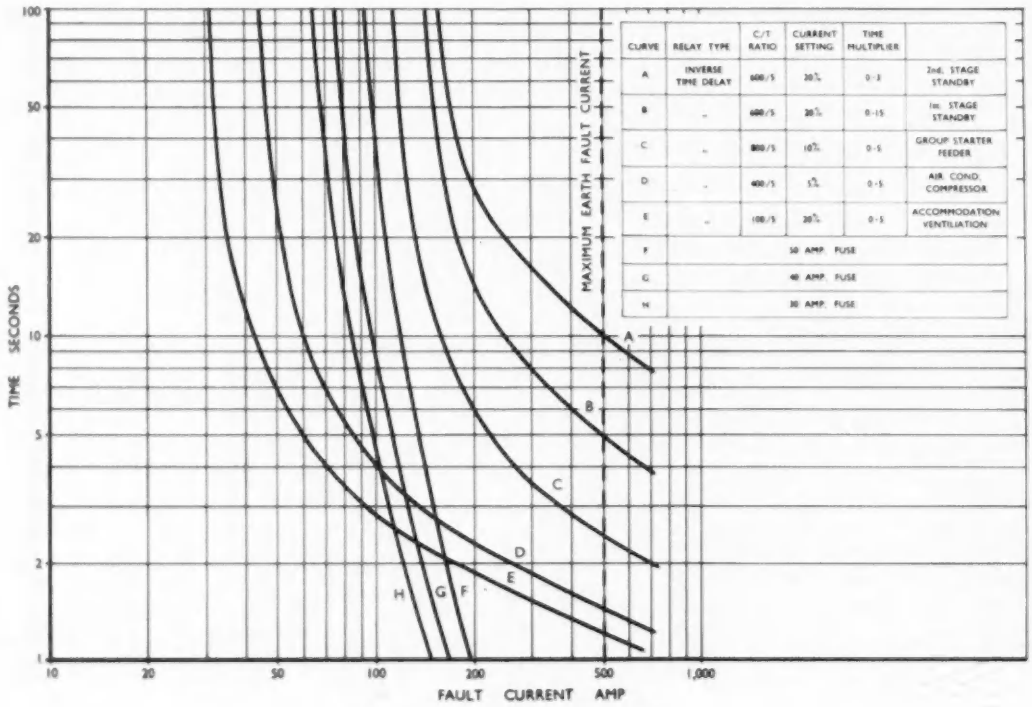


Fig. 13.—Earth fault protection curves.

operation, which are installed on the alternator neutral connections. There are two of these relays, one with approximately double the operating time of the other. The one with the shorter operating time trips the non-essential circuits and the other trips the alternators.

The relays prevent excessive damage due to sustained earth faults, thereby reducing the fire risk, and also protect the earthing resistor against overheating.

Referring again to the plant on the "Bergensfjord", an examination of fuse characteristics and desirable

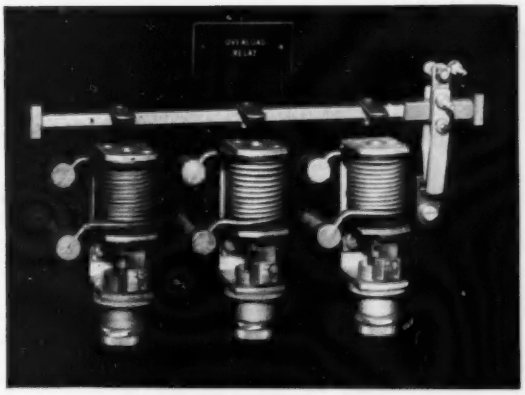


Fig. 14.—Saturable-core overload relay.

relay characteristics showed that a 50 amp fuse is the largest fuse which can be used satisfactorily for earth fault protection. Fig. 13 gives the characteristics of this and several smaller fuses ; also characteristics of various relays which may be in cascade with these fuses.

In selecting relay settings and fuses, a similar principle is applied to that explained more fully for overcurrent protection.

It will also be seen from fig. 13 that relays with settings to curves *D* and *E* are not suitable for use in series with fuses, but that they are suitable for use in series with an instantaneous earth fault relay with a setting less than 30 amp or 20 amp respectively. Curve *C* is quite suitable for use in series with fuses and the back-up protection curves *A* and *B* are suitable for use with any of the curves *C*, *D* and *E* or with any of the fuses.

Lighting and Domestic Services.

For lighting circuits and many of the domestic supplies an ultimate supply is recommended at 115 volts single phase with the centre point earthed through a high resistance and fault detecting relay. These relays can be arranged to trip the faulty circuit.

It will be noted that the general principle of earthing through a relatively low impedance is not recommended for this section of the distribution system. The reasons for this change of policy are :

(1) There are many small isolated systems, in general feeding non-essential loads ; capacity currents to earth are small and not dangerous.
(2) Any section can be switched out for maintenance without serious inconvenience and certainly without impairing the efficient and safe handling of the ship.
(3) High transient voltages cannot occur on these small sections of the network.
(4) Each section will have a low breaking capacity and simultaneous faults on each pole of the system will not result in very heavy fault currents.

RELAYS.

The use of a.c. distribution on ships together with the ever-increasing application of electrical energy for auxiliaries makes it necessary to adopt rather more accurate and delicate relays than had been the custom up to some 10 years ago. During this period an extensive range of relays has been developed which are giving very good service afloat.

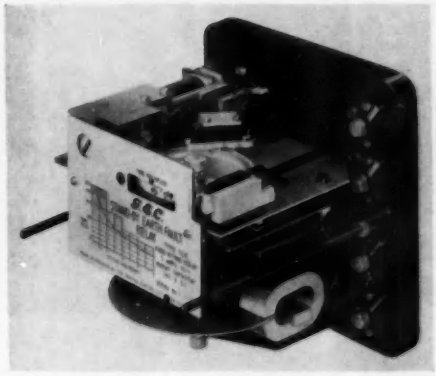


Fig. 15.—Standby earth fault relay.

The types most commonly required are :

Overcurrent relays of magnetic, thermal and induction pattern.
Differential relays.
Wattmetric relays for power measurements and for detecting the direction of power flow.
Earth leakage relays both magnetic and induction pattern.

These instruments must be unaffected by rolling and pitching, they must withstand a reasonable amount of vibration and shock without becoming unstable and they must be easy to maintain. Representative relays are shown in fig. 8, 9, 14 and 15.

The Jamadoba Central Coal Preparation Plant, India

By H. G. HAGUE, M.INST.F., and PHILIP RABONE, A.R.S.M., D.I.C., M.I.M.M.,
Fraser & Chalmers Engineering Works.

Fig. 1.—Jamadoba coal preparation plant.

IN pursuance of a long-term policy for ensuring an adequate supply of metallurgical coal for present requirements and future developments, the Tata Iron & Steel Co. Ltd. planned to install coal preparation plants in districts where suitable coking coals have been found within reasonable distance of the steel works. The first plant was erected at West Bokaro Colliery about 275 miles north-west of Calcutta.* It was designed and constructed by the Fraser & Chalmers Engineering Works of the G.E.C., and was put into commission in March, 1951. The second plant (fig. 1) is situated at Jamadoba in the Jharia coalfield, some 160 miles by rail west of Calcutta, one of India's most important deposits of coking coal. This contract, also, was given to the Fraser & Chalmers Engineering Works. The plant was designed in the Works at Erith, where all the machinery was manufactured exclusive of the electrical equipment, which was supplied by the Witton Engineering Works. The buildings and most of the structural work were made and erected locally in collaboration with The General Electric Co. of India Ltd., and the plant was put into commission in September, 1952.

* *G.E.C. Journal*, Vol. 21, pp.79-90, April, 1954.

CHARACTERISTICS OF RAW COAL.

The seams in the Jamadoba area are high in ash and very difficult to wash. By British standards they would not be considered suitable for metallurgical coke. Nevertheless, in the absence of coals of high grade within practicable distance of the steel works, they constitute an important source of supply for the blast furnaces of the Tata Iron & Steel Co. Ltd. Fortunately the iron ore is of very high quality and the furnaces can be operated economically with coke containing up to 22 per cent of ash. This grade of coke is obtainable from Jamadoba coals when cleaned to 14-15 per cent of ash.

The characteristics of the coal which at present constitutes the main feed to the Jamadoba plant—seams 16 and Jorapukur—are given in Table 1. In common with the other seams in the area, which have similar characteristics, it consists of bands of high-ash coal, mainly durain, and low-ash coal consisting of clairain and fusain, which are much more friable than the durain and break up more readily in consequence. The cleaner fractions therefore tend to concentrate in the fines. This is clearly indicated in the table, the fine coal fraction having a much lower ash content than the raw coal.

Characteristic washing curves are shown in fig. 3. The slope of the differential curve is too steep and too even throughout its length for easy washability. It would be virtually impossible to produce a coal of the required ash content in jigs, and it is a very difficult operation even in a heavy-medium separator, as the density of the medium has to be regulated within the limits of about $\pm 0{\cdot}01$ of the required operating specific gravity. This accuracy of control is attainable with the Chance process. Moreover, the separation can be made with much of the coal feed as fine as $\frac{1}{16}$ in. although the capacity is considerably higher if the minimum size is set at $\frac{1}{8}$ in.

Table 1 shows that an $\frac{1}{8}$ in. $\times$ 0 fraction can be screened out of Jamadoba coal with an ash content of about 15 per cent. From the 3 in. $\times$ $\frac{1}{8}$ in. oversize a clean coal containing 13-14 per cent of ash is obtainable as float at a specific gravity between 1·40 and 1·45. This, when mixed in with the unwashed $\frac{1}{8}$ in. $\times$ 0 fraction, would thus give a product containing slightly less than 15 per cent of ash. By taking off a middling at a somewhat higher specific gravity and crushing the coarser portion, additional coal would be released and the yield of clean coal would be increased correspondingly. There would remain a fine middling with about 30 per cent of ash which could be used locally for steam-raising or for making soft coke for domestic consumption. The Jamadoba plant was designed on the basis of the above characteristics.

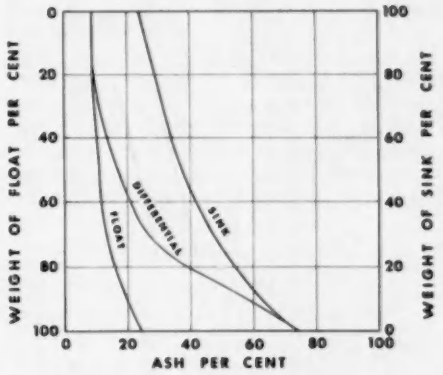


Fig. 3.—Washing curves of Jorapukur seam of Jamadoba Colliery.

COAL PREPARATION PLANT.

The plant was planned for a raw coal input of 300 tons per hour. Although at present it is supplied solely from the Jamadoba Colliery, it has been laid out as a central plant, and eventually all the coal from the Tata's collieries in this area will be treated there.

Fig. 1 and 2 are general views of the plant. The flow of coal is shown in fig. 4. The coal from the pit is brought by conveyor belt to three bunkers of 200 tons each, which enable different classes of coal to be stored separately and blended as required for washing. Space has been left for a fourth bunker and also for a wagon tippler to take coal coming in by rail from neigh-

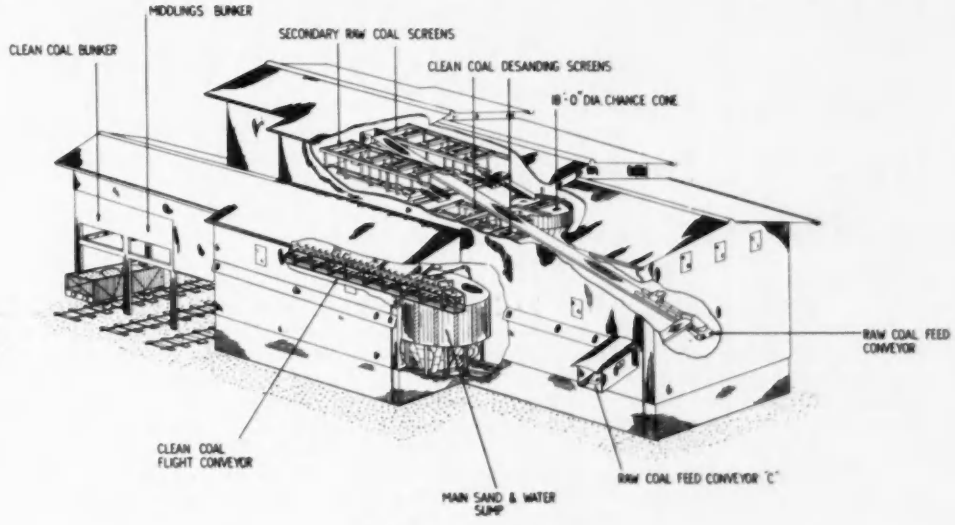


Fig. 2.—Layout of the plant.

TABLE 1.

WASHABILITY TESTS ON JAMADOBA COAL.

Sample : 3 in. × 0 raw coal containing 22·70 per cent ash.

Procedure : ¼ in. × 0 dust was screened out. A float-and-sink separation was made on the 3 in. × 0 fraction. The 3 in. × 1 in. fraction of this separation between s.g. 1·45 and 1·59 (middlings) was crushed through 1 in. and the ¼ in. × 0 fraction was added to the original dust. Float-and-sink tests were then run on the 1 in. × ¼ in. fraction of the crushed middlings and the various specific gravity fractions were added to those of the original separation.

Size of Fraction	Float at 1·40		Sink at 1·40 Float at 1·45		Sink at 1·45 Float at 1·50		Sink at 1·50 Float at 1·55		Sink at 1·55 Float at 1·59		Sink at 1·59		Raw Coal	
	Weight %	Ash %	Weight %	Ash %	Weight %	Ash %	Weight %	Ash %	Weight %	Ash %	Weight %	Ash %	Weight %	Ash %
3 in. × ¼ in.	41·60	12·70	15·42	21·40	3·11	26·30	3·92	30·10	3·24	35·50	17·73	50·00	85·02	24·58
¼ in. × 0 dust													14·98	14·10
3 in. × 0 raw coal													100·00	23·01

ANALYSIS OF FLOAT-AND-SINK SEPARATION.

Specific Gravity Fraction	Clean Coal		Corresponding Middlings		Reject		Clean Coal with ¼ in. × 0 Dust mixed in		Specific Gravity Fraction
	Weight %	Ash %	Weight %	Ash %	Weight %	Ash %	Weight %	Ash %	
Float at 1·40	41·60	12·70	25·69	25·10	—	—	56·58	13·24	Float at 1·40
Float at 1·45	57·02	15·03	10·27	30·65	—	—	72·00	14·85	Float at 1·45
Float at 1·50	60·13	15·62	7·16	32·54	—	—	75·11	15·32	Float at 1·50
Float at 1·55	64·05	16·52	3·24	35·50	—	—	79·03	16·06	Float at 1·55
Float at 1·59	67·29	17·43	—	—	—	—	82·27	16·83	Float at 1·59
Sink at 1·59	—	—	—	—	17·73	50·00	—	—	Sink at 1·59

bouring collieries. Provision has been made for storing coal from the other collieries on the ground behind the bunkers in the event of the plant being out of action, and for reclaiming it subsequently.

Coal is drawn from the bunkers by two travelling Sherwen vibrating feeders, 48 in. wide × 10 ft. long. Each can, if required, handle 300 tons of coal per hour. The feeders deliver the coal to conveyor belt *A* and thence by conveyors *C* and *D* to two primary shaking screens. The top deck of each is 7 ft. wide and is provided with 3 in., 1 in. and ¾ in. round holes. The bottom deck is 8 ft. 6 in. wide and has ⅜ in. round holes. The 3 in. oversize goes to apron conveyors *E* and *F* where wood, tramp iron, etc., are removed, the coal from the cone. If required, however, it can be by-passed to a dust bunker with a capacity of 130 tons, from which it is loaded by Redler conveyor *R* into railway wagons.

CHANCE PROCESS.

The Chance coal-cleaning process is based on the fact that the admission of water into a bed of sand is capable of converting it into a dense fluid medium. The specific gravity of the medium is adjusted to the density at which the coal floats and the refuse sinks. An extra adjustment, described later, enables a denser layer to be formed below the surface of the medium on

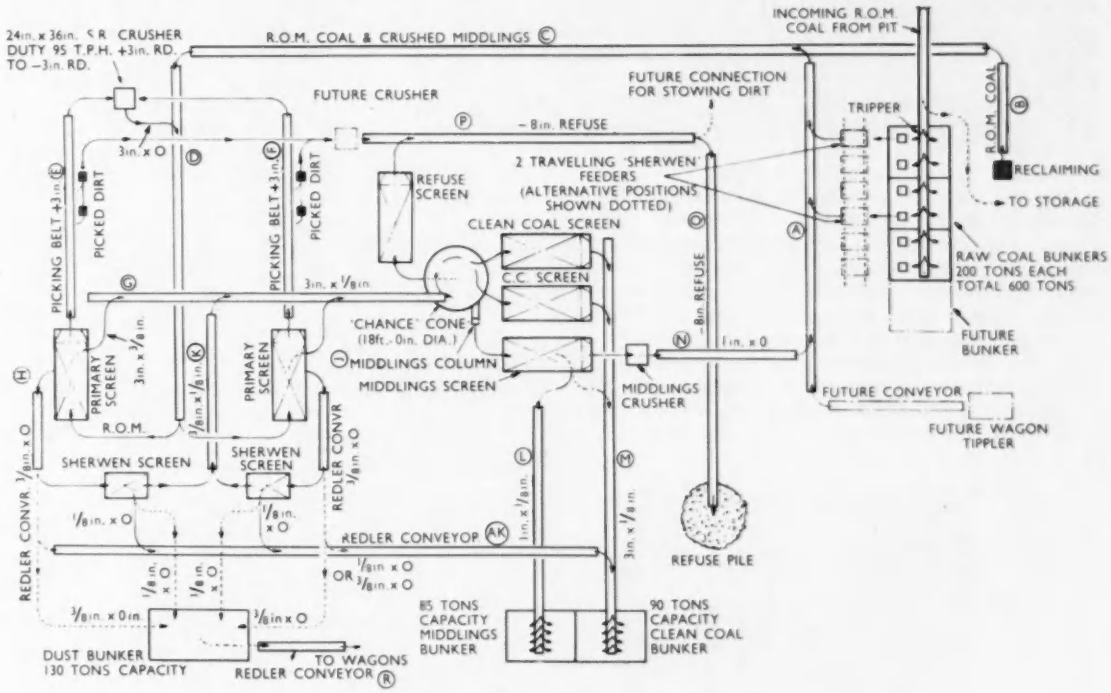


Fig. 4.—Flow of coal at the Jamadoba plant.

coal passing to a 24 in. × 36 in. Pennsylvania single-roll crusher, which reduces it below 3 in. size, dropping it on to conveyor *D* for return to the primary screens.

The 3 in. × ⅜ in. fraction is taken by conveyor *G* to the Chance cone. The ⅜ in. × 0 undersize is elevated by Fraser & Chalmers Redler conveyors *H* and *J* to two Sherwen vibrating screens, each 4 ft. wide × 10 ft. long, fitted with ⅛ in. woven-wire screen cloth. The ⅜ in. × ⅛ in. oversize drops on to conveyor *K* and joins the 3 in. × ⅜ in. fraction on conveyor *G*, passing with it to the cone. The ⅛ in. × 0 undersize, which does not need cleaning, is normally transported by Redler conveyor *AK* to conveyor *M*, dropping on to and mixing with the clean which middlings can be collected and discharged through a special column.

The construction of the cone in which the separation is made can be seen from fig. 6. Exterior views are shown in fig. 5, 7 and 9. In the Jamadoba plant the cone is 18 ft. in diameter at the top. It has a slow-speed agitator, running at 6 r.p.m., to give the medium a circular motion. A middlings discharge column of square section is fitted about halfway down the cone ; it is clearly shown in fig. 6 and 9. A refuse discharge chamber is situated at the bottom.

Sand and water from the main sand sump are pumped in at the top of the cone at a comparatively high specific gravity. Water is also pumped into the

cone at several levels (fig. 9), the quantity admitted at each level being regulated by special density control valves to produce an even gravity in the cone without the formation of any " dead spots " in the suspension ; the amount is sufficient to give a slow overflow at the top of the cone. The water admitted at and above the level of the middlings outlet is adjusted to the specific gravity at which the clean coal floats. Below the outlet it is controlled at the specific gravity at which the middlings float and the refuse sinks. These gravities are 1·43 and 1·58 respectively for the coal that is at present being treated.

The raw coal is fed into the top of the cone. The clean coal floats on the medium and is carried round by action of the agitator to the discharge point, where it overflows on to two shaking screens for de-watering and de-sanding (fig. 8). The middlings that collect on the layer of higher specific gravity at the middlings outlet level are carried by a stream of water up the column, which rises to the height of the top of the cone in order to maintain the medium at that level. They overflow on to a de-watering and de-sanding screen similar in design to the clean coal screen.

The refuse chamber discharges the sink material at the rate at which it collects in the bottom of the cone. It can be seen in fig. 7. The chamber is provided with upper and lower gates and a filling valve, all of which are opened and closed automatically, being actuated by compressed air at 80 lb. per sq. in. supplied by a two-stage compressor with a capacity of 200 cu. ft. of free air per min. The flow of air is governed by three solenoid-operated piston valves controlled by two electric timers, one for the upper gate and filling valve

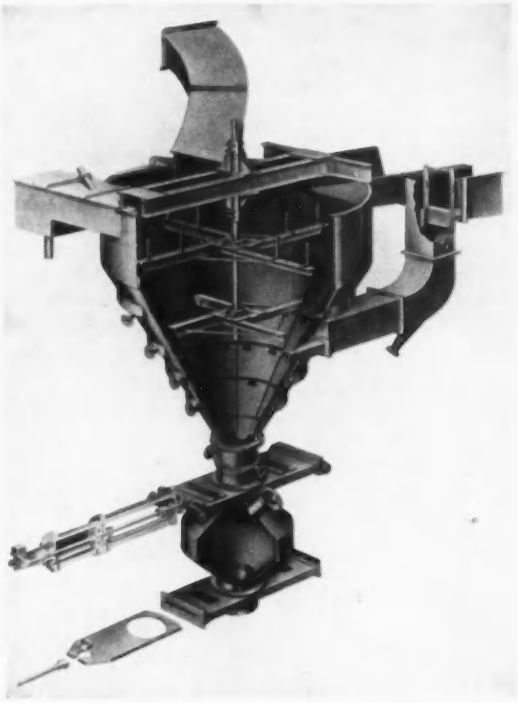


Fig. 6.—Diagram of Chance cone.

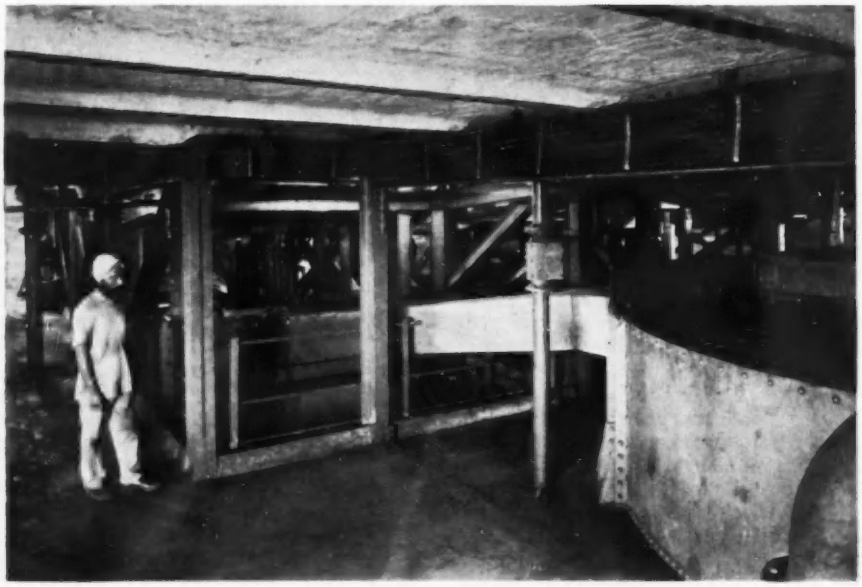


Fig. 5.—Top of cone, showing coal overflow launder to clean coal screens.

and the other for the lower gate. A limit switch regulates the length of travel of each gate. In operation, the timer opens the upper gate to allow the refuse that has collected above it to drop into the chamber, closing it again after a predetermined interval; the lower gate remains closed during this period.

The lower gate, actuated by the second timer, opens after a short interval and discharges the contents of the chamber on to a de-sanding screen. It closes after a predetermined interval and the filling valve then opens, admitting water into the chamber, which is now closed top and bottom. When the chamber is full, a pressure switch at the top closes the circuit of the first timer, enabling the upper gate to open at the appropriate time, and the cycle is then repeated. In this way the refuse is discharged automatically at the rate at which it collects without interfering with the levels or with the operation of the cone. The timers can be set independently to keep their respective gates open for any desired period and for any time interval between the closing of one gate and the opening of the other.

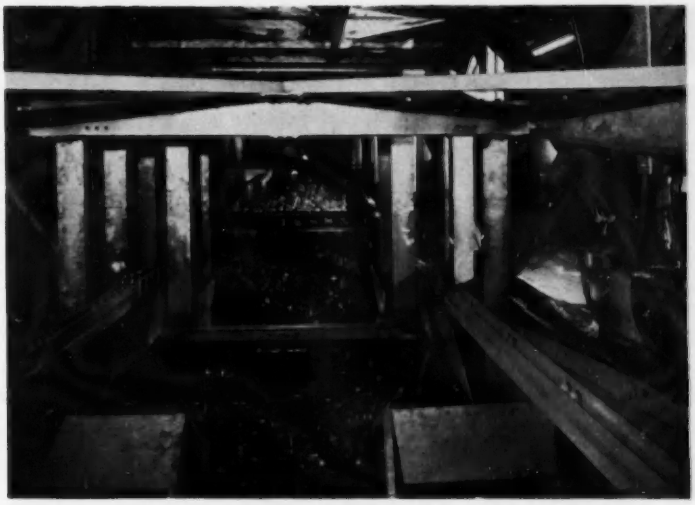


Fig. 8.—Clean coal screen.

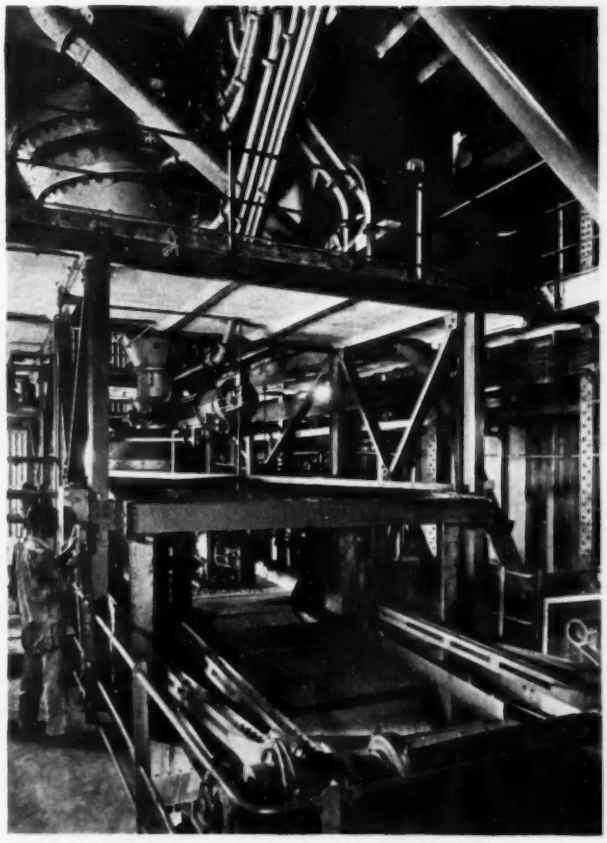


Fig. 7.—Base of cone, showing refuse chamber with discharge gates and de-sanding screen.

The de-watering and de-sanding screens are similar in design to the raw coal primary shaking screens. The top decks are 7 ft. and the bottom decks 8 ft. 6 in. wide. The top decks of the clean coal and refuse screens have $\frac{1}{2}$ in. round holes and those of the middlings screen have $\frac{1}{2}$ in., $\frac{3}{4}$ in. and 1 in. holes in order to separate a 3 in. $\times$ 1 in. product for re-treatment. All the lower decks are fitted with 1 mm. wedge-wire screens of stainless steel.

From the clean coal and middlings screens the sand and water flow direct to the main sand sump (fig. 10); from the refuse screen they drop into a subsidiary sump, from which a sand pump elevates them to the main pump. Clear water overflows the latter into a separate compartment, whence it is pumped back to the cone through the density control valves and inlet pipes. The sand collecting in the bottom of the main sump is pumped back at a comparatively high density into the top of the Chance cone. Thus, the sand and water circuits are closed and the operation of the cone is fully automatic.

The clean coal from the screens is elevated by a flight conveyor *M* (fig. 4) to a bunker with a capacity of 90 tons, from which it is loaded into railway wagons for transport to the coke ovens at Jamshedpur. The 1 in. $\times$ $\frac{1}{8}$ in. middlings are taken by a second flight

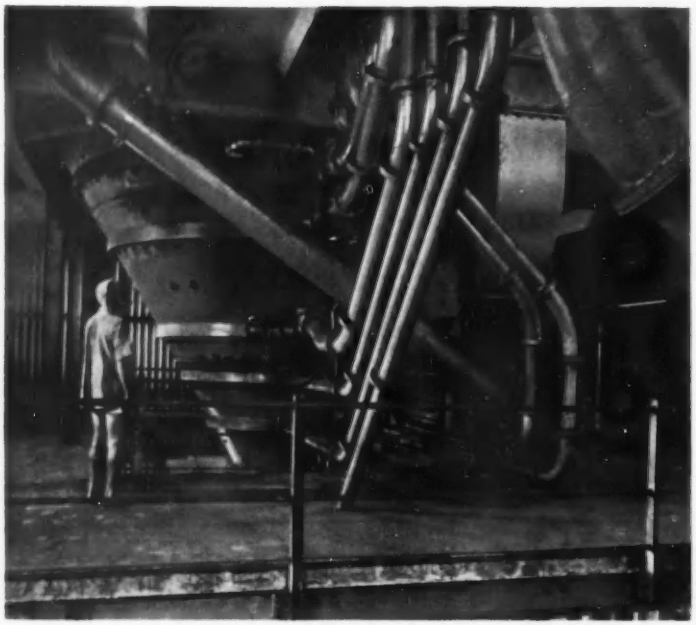


Fig. 9.—Water inlet pipes and middlings column.

conveyor *L* to a middlings bin alongside the other; provision has been made for it to be by-passed, when required, to the clean coal bunker. Both flight conveyors are arranged so that they trim the bunkers automatically as they pass over the top. The 3 in. × 1 in. fraction of the middlings drops from the upper deck of the screen into a 24 in. × 36 in. Pennsylvania single-roll crusher, which reduces it all below 1 in. size. The crushed middlings are returned to the circuit on conveyors *N* and *A*, joining the main stream of raw coal feed on conveyor *C*. The discharge of the refuse screens is transported by conveyors *P* and *Q* to the refuse dump.

The performance of the plant has come up to expectations. In the acceptance test, the results of which are tabulated in Table 2, the total errors were 4 per cent lower than the guarantee and all the coal products were of acceptable grade.

CONTROL OF PLANT.

Under the direction of Mr. H. K. Sen, Coal Preparation Superintendent of the Tata Iron & Steel Co. Ltd., a laboratory has been established and a comprehensive sampling system organised for checking and regulating the operation of the plant. The laboratory, which is adjacent to the plant, is equipped to carry out all routine analyses and any special investigations that may be necessary. It is very well fitted out, the equipment including a standard Fraser & Chalmers float-and-sink test machine, a jaw crusher and sample pulveriser, a chemical balance, electric muffles and drying ovens, sample rifflers, a sieving machine with a range of standard screens, and the necessary ancillary equipment for the size reduction and analysis of the samples.

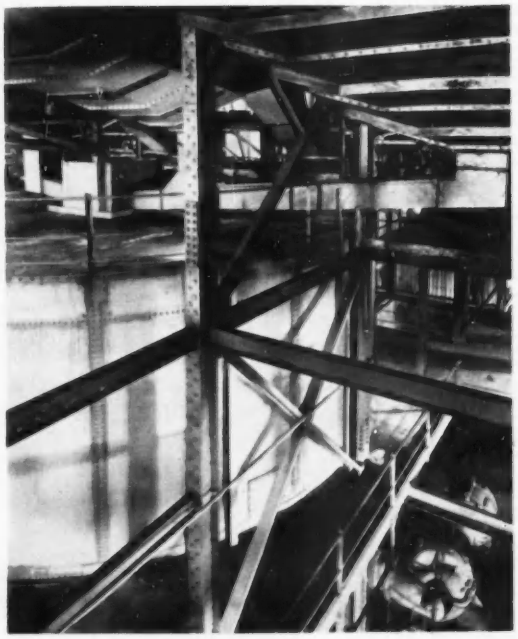


Fig. 10.—Main sand sump and water circulating pumps.

The raw coal entering the plant and the various products are sampled regularly at predetermined intervals and the samples are sent daily to the laboratory, where they are prepared for analysis. Each sample is recorded as it comes in, and, in addition, a log book is kept in which the results are entered against the valve adjustments regulating the specific gravity of the sand medium in the Chance cone over the period covered by each sampling period. A check is also kept on the sizing of the sand, which is regulated more or less as follows :

Retained	on	30	mesh	(B.S.I.)	4	per cent	
„	„	44	„	„	30	„	„
„	„	85	„	„	90	„	„
„	„	100	„	„	94	„	„
Passing		100	„	„	6	„	„

The sand is obtained from a nearby river, but it has to be classified in order to yield a product of the required size range. Regular samples are therefore taken of the classifier discharge and sent to the laboratory for sizing analyses.

TABLE 2.

ACCEPTANCE TEST AT JAMADOBA COAL PREPARATION PLANT INCLUDING CRUSHING AND RE-WASHING OF MIDDLINGS.

FEED TO PLANT : 2,563 tons of raw coal, containing 23·05% ash, at rate of 264 tons per hour.

RESULTS OF TEST RUN.

Products	Tons	Weight %	Ash %
Raw coal feed	2,563	100·0	23·05
$\frac{1}{8}$ in. × 0 dust screened out	513	20·0	18·2
Feed to Chance cone, 3 in. × $\frac{1}{8}$ in.	2,050	80·0	24·3
Products from Chance cone :			
Clean coal 3 in. × $\frac{1}{8}$ in.	1,281	50·0	14·0
Middlings 1 in. × $\frac{1}{8}$ in.	394	15·4	32·2
Refuse 3 in. × $\frac{1}{8}$ in.	375	14·6	51·0
	2,050	80·0	24·3
Final products :			
Clean coal and $\frac{1}{8}$ in. × 0 dust	1,794	70·0	15·2
Middlings	394	15·4	32·2
Refuse	375	14·6	51·0
	2,563	100·0	23·05

SINK-AND-FLOAT TESTS ON PRODUCTS FROM CHANCE CONE.

Products	SP.GR.	Averages of 12 Samples	Raw Coal Basis	Bulk Samples	Raw Coal Basis	Guarantee	SP.GR.
		Weight %	Weight %	Weight %	Weight %	Weight %	
Clean coal 3 in. × $\frac{1}{8}$ in.	S 1·43	3·9	2·43	4·2	2·62	5·0	S 1·45
Middlings 1 in. × $\frac{1}{8}$ in.	F 1·43	15·0	2·88	16·1	3·09	4·0	F 1·45
	S 1·58	15·0	2·88	18·7	3·59	3·0	S 1·60
Rejects 3 in. × $\frac{1}{8}$ in.	F 1·58	6·7	1·22	4·5	0·82	2·0	F 1·60
Total misplaced material			9·41		10·12	14·0	

Ash determinations and float-and-sink tests are carried out daily on the samples of washery products. The daily sample of raw coal, however, is accumulated and analysed once a week. In addition, a sample of the final product of washed coal mixed with unwashed dust is taken from each railway wagon as it is loaded. From these a composite sample is made, representing the whole day's production, which is analysed for its ash content. The wagons are again sampled individually on arrival at the Jamshedpur Steel Works, but there each sample is analysed separately. As a general rule the average ash analysis does not differ from that of the Jamadoba composite sample by more than 0·4 per cent and it is often within less than 0·1 per cent. This is a good indication of the care that is taken in sampling and analysing the plant products and of the efficiency of the system.

The regular analyses of the necessary samples, including the sand, and their correlation with the operating adjustments in the laboratory log book enable a close check to be kept on what is, in fact, one of the most difficult separations that has been carried out in a Chance cone. The control system was established by Mr. H. K. Sen and the successful operation of the plant is largely due to his organising ability and attention to detail.

ACKNOWLEDGMENT.

The authors are indebted to Mr. S. C. Ghosh, Superintendent of Collieries of the Tata Iron and Steel Co. Ltd., for permission to publish this article. Much of the credit for the successful establishment and operation of the central coal preparation plant at Jamadoba is due to his keen and active interest in supplying the steel works at Jamshedpur with the products that are needed for the successful operation of the blast furnaces.

FLUORESCENT LIGHTING IN REGENT STREET, LONDON

G.E.C. "Four-Eighty" and vertical lanterns in the new Regent Street lighting installation.

New Trains for Suburban Routes in the London Midland Region

By J. C. TURRALL, A.M.I.E.E. and W. E. LEWIS, A.M.I.E.E.,
Traction Department, Witton.

WATFORD was designated a " principal station " from the earliest days of the London and Birmingham Railway and was served by the first- and second-class trains. Originally of importance as a market town, in later years it attracted various industries, but expanded even more rapidly as the centre of a dormitory area for London. Branch lines from Watford Junction to Croxley Green, Rickmansworth and St. Albans in due course added to the volume of passenger traffic so that this busy centre, just over 17 miles from Euston, was chosen as the outer suburban terminus for the electrification planned by the London and North Western Railway, into which the London and Birmingham had been merged in 1846.

The L. & N.W.R. electrification programme began in 1914, with the line from Willesden to Earl's Court, following this with Broad Street-Willesden-Richmond in 1916 and Willesden-Watford in 1917. Further work was suspended in the closing stages of the first World War and the Willesden-Euston section was not electrified until 1922, the branch line from Watford Junction to Watford West and Croxley Green and the curve for through-running to the branch from the London direction, dispensing with the need for reversal at Watford, being converted for electric traction at the same time.

Fig. 1.—Two of the new three-coach sets at Stonebridge Park depot.

An important complement to the Euston-Watford electrification was the extension of Bakerloo Line tube services to Watford over the same tracks, which had begun in 1917. All the lines mentioned were electrified on the third- and fourth-rail system at 630 V d.c., so that no difficulty arose with the through running of tube stock using this method of supply.

Electrical equipment for trains on these routes was first supplied by the G.E.C. in 1926 to the London

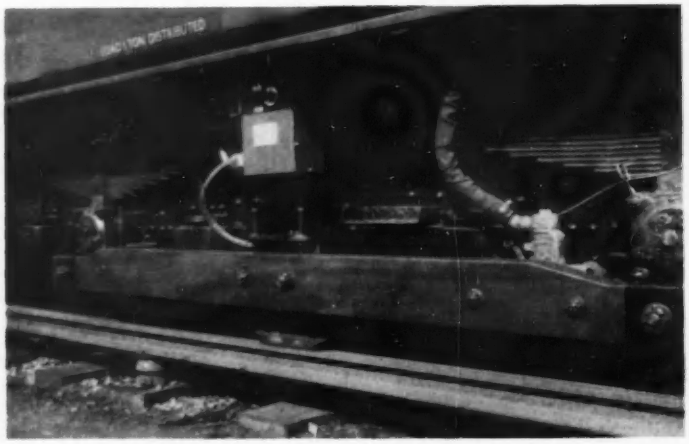


Fig. 2.—Positive shoegear and shoe isolating switch.

Midland and Scottish Railway, of which the former L. & N.W.R. had become the major constituent when the railways were grouped in 1923. Further orders were received in 1927 and 1932 as more trains were built, the total numbers of vehicles equipped up to the formation of British Railways in 1948 being 25 motor coaches, 25 driving trailers and 22 trailers.

In 1955 it was decided to replace much of the existing rolling stock with new trains built to British Railways designs and an order was placed with the Company for the complete electrical equipment of 57 three-coach sets. The first of these went into service in May this year. They operate on all the London Midland Region electrified suburban lines, the extent of which is as already described except that the Willesden-Earl's Court passenger service was withdrawn early in the second World War and that on the Rickmansworth branch in 1952. Post-war development has greatly increased the importance of Watford as an industrial centre and the electric trains serve as feeders from a wide area for main line expresses calling at Watford Junction.

Trains of the new stock (fig. 1) are formed of up to three units operating in multiple. Each unit consists of a motor coach, trailer and driving trailer, providing second-class accommodation for 256 passengers in all. Motor coaches and driving trailers are of the open saloon type with centre gangway. The seat ends slope from the floor towards the body sides to allow maximum width in the gangway at shoulder height while still providing the widest possible seating room. At the end partitions the seats extend the full width of the vehicles. Trailer coaches are divided into compartments with six-a-side seating.

The rolling stock was built at the British Railways Carriage and Wagon Works at Eastleigh and the motor bogies at Ashford.

POWER AND CONTROL CIRCUITS.

Positive and negative shoegear is provided on both bogies of the motor coach and on the bogie at the cab end of the driving trailer, all being interconnected by bus lines. On seven train units a new design of shoegear is fitted which has been developed to improve current collection, reduce wear and eliminate the noise emitted by normal types of gravity shoegear when not in contact with the conductor rail. Rubber is used both as a noise-damping and springing medium, André-Neidhardt units being employed at the joints of the links, which are arranged to rest on rubber cushions when in the released position. No shoe fuses are used, but each set of shoes is provided with an isolating switch of new design (fig. 2).

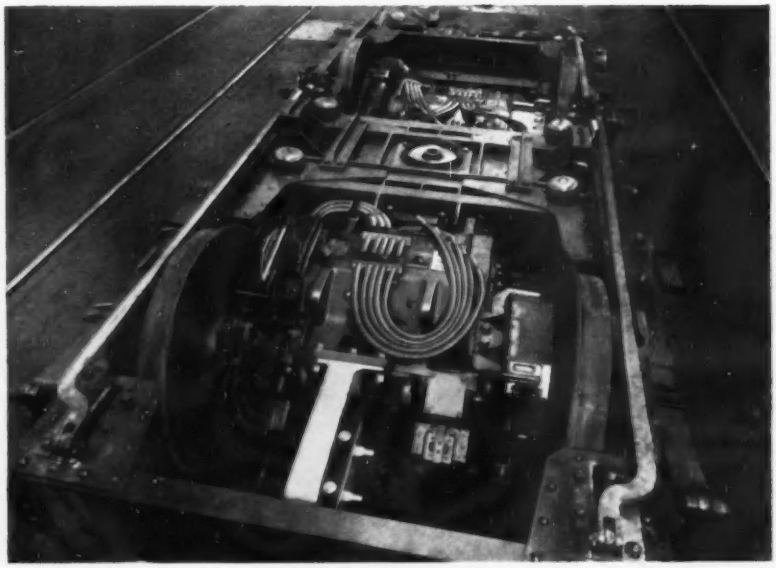


Fig. 3.—Motor bogie.

Power is fed to bus lines running throughout each unit which supply the four motors, the auxiliaries and the heaters on the motor coach, and the heaters on the trailer and driving trailer. Bus line connections between coaches and units are made by jumpers and power receptacles of a new design, in which line contact with the plugs is obtained by the use of spring-loaded fingers.

Ratings of a unit (four motors) are as follows :

	Full field	*Weak field*
Continuous	540 h.p.	600 h.p.
One-hour	680 h.p.	740 h.p.

The two motors in each motor coach bogie (fig. 3) are connected permanently in parallel and all are fed through a double-pole isolator (fig. 5). Either pair can be cut out of circuit by a hand-operated motor cut-out switch, the handle of which is seen on the end of the centre equipment case in fig. 4. The motors are axle-hung and self-ventilated, drawing in air through protected openings on the tops of the frames, and drive the axles through gearing with a ratio of 16/74. Wheel diameter is 3 ft. 4 in.

The nose of each motor rests on a rubber block carried on a bracket welded to the bogie transom. This block, and rubber springs below the bracket, are held in compression by the bolts which pass through them to secure the nose to the bracket, so that the upward and downward thrust of the nose and lateral forces are both rubber-cushioned, the precompression ensuring that all rubbers are under compression under all conditions.

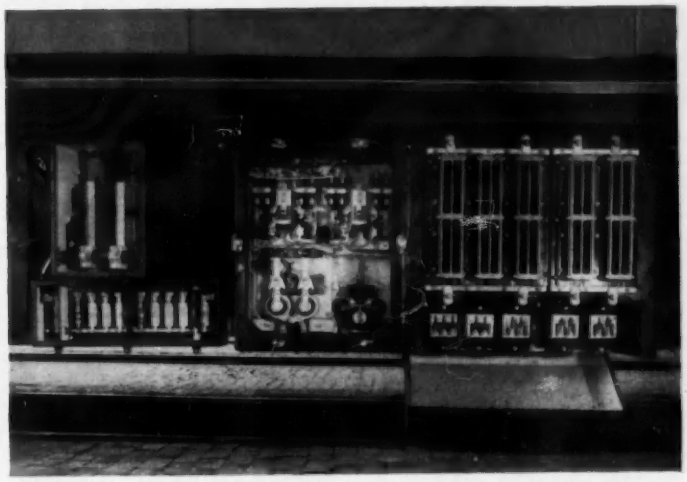


Fig. 5.—Motor isolator (left) and equipment case containing main relays and line contactors.

The main electro-pneumatic contactor control equipment, relays, motor isolator and motor cut-out switch are housed in three equipment cases on the motor coach underframe (fig. 4). The contactor interlocks are accessible from the front of the cases and are protected by " Perspex " covers. The field control and reverser switches are air-powered, cam-operated groups employing contact elements of new design. The motor cut-out switch is similar but hand-operated. Fig. 7 shows the equipment case which contains these cam groups together with the 630 V auxiliary contactors.

A diagram of the power circuits is shown in fig. 6. By connecting the two groups of motors in series or

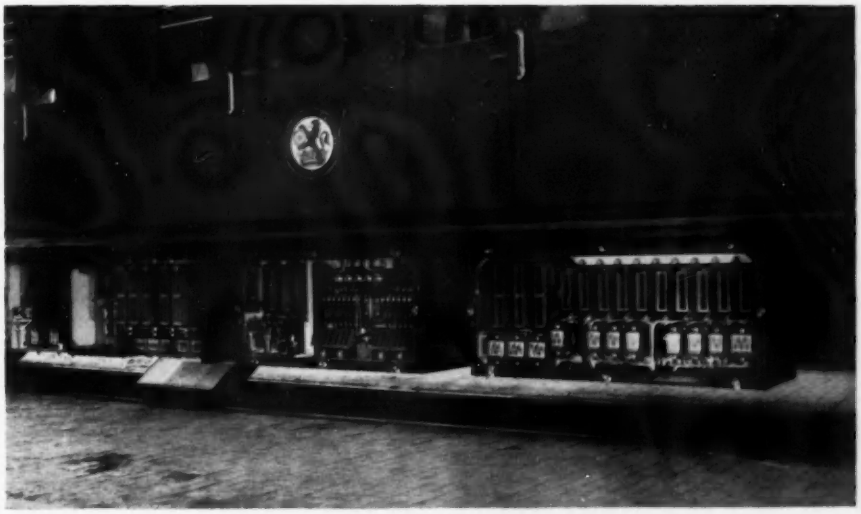


Fig. 4.—The three underframe equipment cases.

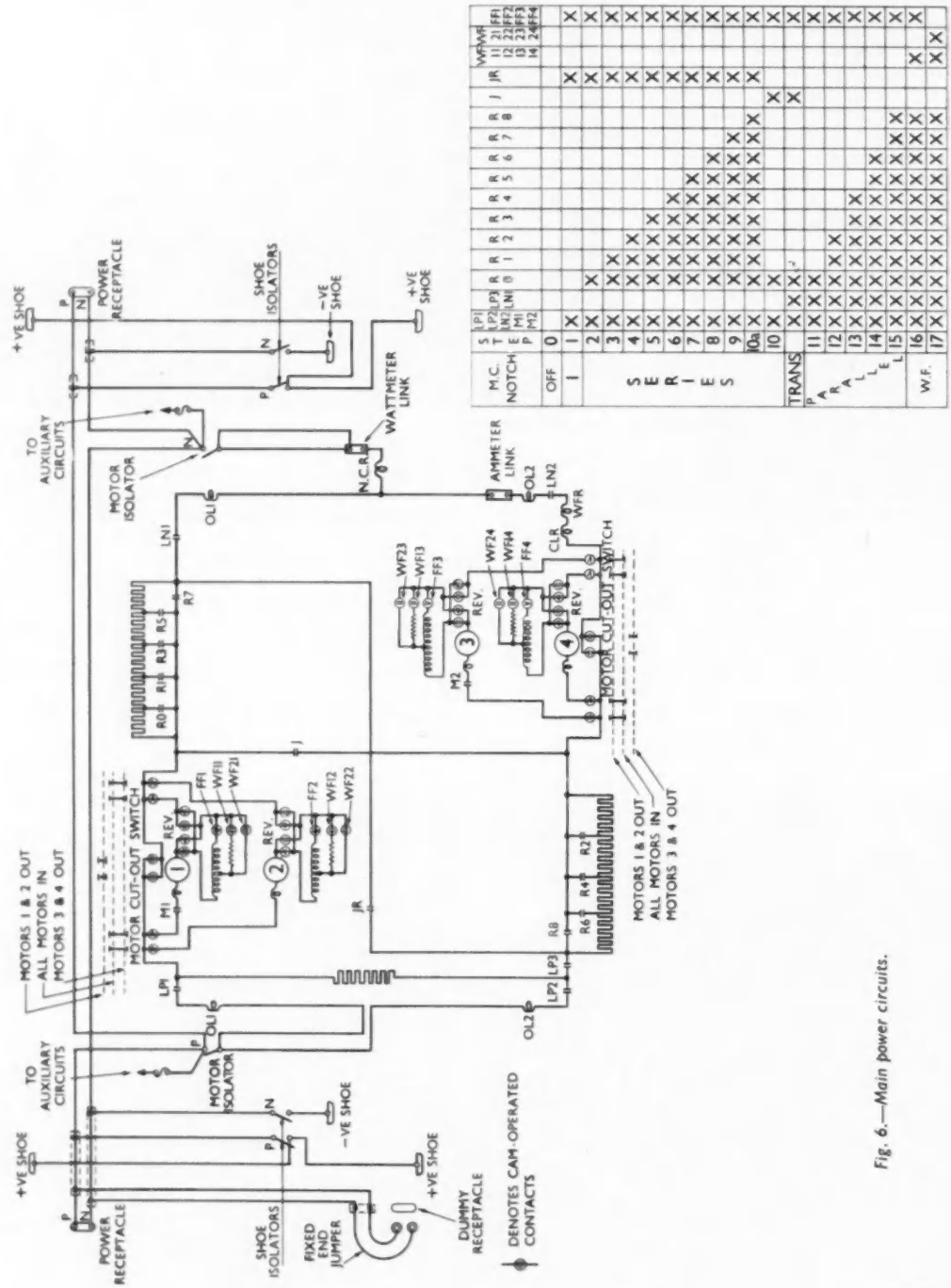


Fig. 6.—Main power circuits.

parallel (simplex control), control is obtained with a single equipment, as compared with the two equipments required with individual series/parallel control

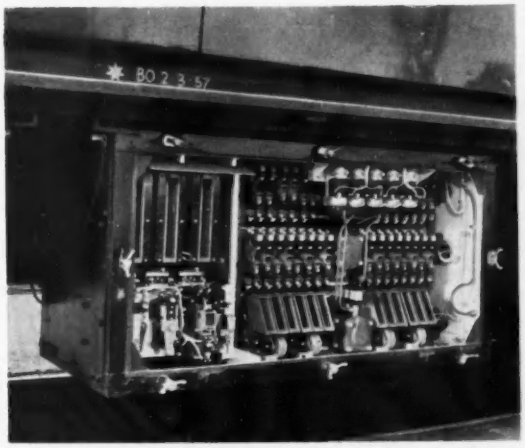


Fig. 7.—Air-operated cam groups for field control and reversing, and hand-operated cam group of motor cut-out switch.

of two pairs of motors (duplex control). The first master controller notch provides for shunting movements, the motor groups being in series and all resistance in circuit. On the second notch automatic acceleration to full series is effected. Bridge transition and automatic acceleration to full parallel take place on the third notch, the resistance sections in each group being short-circuited in pairs. In order to improve the balance of the bridge, one section of resistance which is in circuit on the first notch is not reinserted at the transition stage. Further increase in speed is obtained by moving the controller to the weak-field position, on which, under the control of a separate weak-field relay, a portion of each field is first shunted by a resistance and the fields are finally weakened by tapping.

There are two forward positions of the reverser handle, the first giving a rate of acceleration of 0·92 m.p.h.p.s. and the second, by energising the shunt coil of the current limit relay through a resistance, giving the normal rate of 1·25 m.p.h.p.s. A third rate is available for emergency use when starting on the 1 in 35 gradient of the Primrose Hill flyunder if a pair of motors has been cut out. It is obtained by placing the reverser handle in the normal rate position and operating a pushbutton to short-circuit part of the resistance in series with the current limit relay shunt coil. The controls in a motor coach driving cab are seen in fig. 8.

When the motor cut-out switch is used to isolate either pair of motors, its contacts modify the control circuit so that all motors in the train accelerate to parallel irrespective of whether the controller is at series or parallel, and the weak-field position is inoperative on the unit with isolated motors. On the affected unit, the normal notching of both groups of resistances is retained.

Each overload relay has two trip coils, one being connected at each end of the associated motor circuit leg. In the event of an overload a protective resistance (which is not used for notching) is brought into circuit to limit the fault current before final rupture takes place. Referring to fig. 6, if the fault occurs in the leg containing motors 1 and 2, *OL*1 operates and its contacts drop out *LP*1 so that the protective resistance is inserted in the fault circuit. *LP*1 " in " interlock then opens *LP*2, *LN*2 and *LN*1 together to clear the fault. If the fault occurs in the leg containing motors 3 and 4, *OL*2 lifts and its contacts open *LP*2 contactor, which transfers the fault current through the protective resistance. *LP*2 " in " interlocks open *LP*3 and *LN*2 contactors to clear the fault. Meanwhile *OL*1 will have tripped when the fault current was transferred, so that *LP*1 opens, followed by *LN*1.

Contacts on the overload relays energise an indicator relay which latches itself in and causes an indicator lamp to light. The lamp remains alight, providing the train line key is in position, after the overload relays have been reset from the driver's pushbutton. The unit in which the fault occurred can therefore be identified at the depot by reinserting the key. After the defect has been cleared the indicating relay is reset by hand.

A no-current relay is arranged to drop out the line

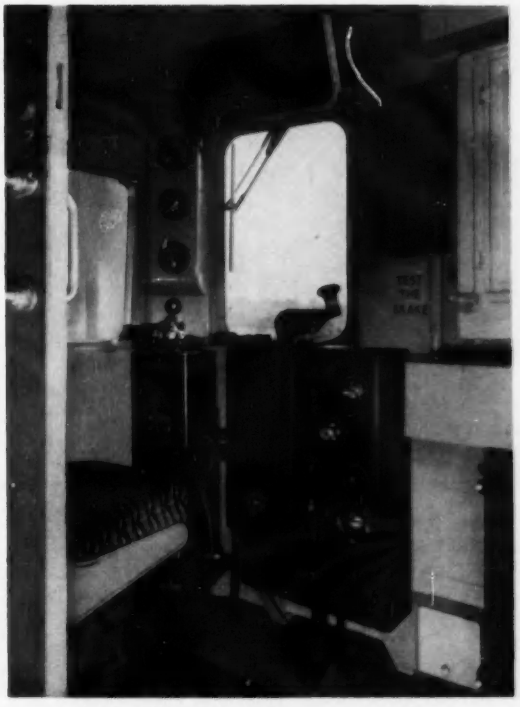


Fig. 8.—Driver's compartment in motor coach.

switches and resistance contactors in case of an interruption of supply. If the interruption is momentary and the controller has been left on any notch, the equipment will notch up automatically to that position when power is restored.

AUXILIARY SERVICES.

The 6 kW motor-generator set, compressor and battery are carried on the motor coach underframe (fig. 9). Provided the motor-generator isolator is closed, insertion of the train line key energises the motor-generator contactor and starts the set on the unit concerned. During daylight running with trains consisting of more than one unit, only the set on the motor coach where the key has been inserted is in operation, but if the passenger lighting is switched on, a contact on the lighting set-and-trip relay energises the motor-generator contactor coils in the other units. The lighting contactor coil is connected across the L.T. generator, so that the contactor will close only when the set is running. Set-and-trip pushbuttons for passenger lighting are fitted in each van compartment.

A battery floats across the 52 V output from the motor-generator set and is of sufficient capacity to supply the control load, and the cab, van, route-indicator and other essential lights of a six-car train for some two hours. Dimming control is provided for the cab instrument lights. Passenger lights are fed direct from the L.T. generator. There are two separately-fused lighting sub-circuits in each car so that a lighting fitting fault may be cleared by its own circuit fuse before the main lighting fuse blows, thus avoiding a general failure of lighting. A cupboard in the motor coach cab houses the majority of the L.T. control equipment, including the voltage regulator, lighting and battery charging contactors.

The compressor in each unit provides the air supply for operating brakes, electro-pneumatic control gear, windscreen wipers and whistles. It is protected by an overload relay with instantaneous trip to protect against motor flashover and a time delay trip to protect against a persistent heavy overload.

Both the M.G. set and the compressor are started direct to line through electro-magnetic contactors, resistances being included in the motor circuits to limit the starting current. The M.G. set motor is protected by 60 amp fuses on the positive and negative sides.

In fifteen of the units the driving trailers are equipped with de-icing fluid reservoirs from which the fluid can be fed to the conductor rails via the shoegear. The supply of fluid is controlled by electro-magnetic valves which can be energised by the operation of de-icing pushbuttons at each driving position when the reversing handle is in either of its "forward" positions. A de-icing relay connected across the E.P. brake trainline opens the circuit to the valves when a brake application is made. Contacts operated by linkage connected to the positive collector shoes are arranged to break the circuit of the associated valve when its shoe is not on the conductor rail.

HEATING.

Heating supplies are taken from the power bus lines in each car, the heaters being connected in groups of two in series. Back-up protection is provided by the main auxiliary fuses on the motor coach or the main heater fuses on the trailer and driving trailer should the crew heat or coach heat fuses fail to clear a severe fault. Passenger heating is selected by the guard by means of pushbuttons in any van compartment and is thermostatically controlled, the thermostat relays and contactors in the trailers and driving trailers being carried in underframe equipment cases. Cab and van heating is controlled by switches in the respective compartments of motor and driving trailer coaches.

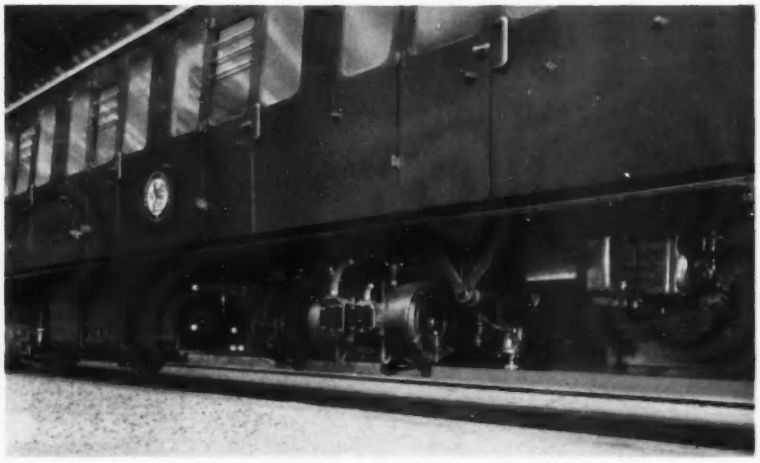


Fig. 9.—Motor-generator, compressor and resistance cases.

ACKNOWLEDGMENT.

Acknowledgment is made to the London Midland Region of British Railways for permission to publish this description of the electrical equipment of the trains and for facilities for taking photographs.

"Im-Plast"—A New Toughened Rubber Material for Battery Containers

By A. L. SPARSHOTT, B.Sc.,
Witton Moulded Insulation Works.

Important developments have taken place in recent years in rubber technology, giving rise to improved toughened hard rubber moulding materials of which "Im-Plast" is an outstanding example. In this article the author discusses the advantage of "Im-Plast" for moulded battery containers and outlines the part played by the Company in its development, concluding with a brief description of the methods of production and testing of battery containers using this material.

THE term "hard rubber" has been applied in the past to rubber compounds, with or without fillers and accelerators, vulcanised or cured with approximately 40 parts of sulphur to 100 parts of rubber. Soft rubber compounds have sulphur in the ratio of up to 3 or 4 parts to 100 parts of rubber. Intermediate proportions of sulphur do not produce the results which might be expected in that the properties of the product do not change progressively as the sulphur proportion is adjusted and in general the compounds resulting from the use of sulphur in proportions between, say, 6 per cent and 30 per cent find no application. Thus there has been a gap in rubber technology in the range of hardness available in rubber compounds.

The only rubber-based materials in the intermediate hardness range were basically soft rubbers carrying a very high filler content and showing poor physical properties, especially abrasion resistance. The high filler content usually consists very largely of clays and leads to a high specific gravity and also to processing difficulties. These arise from the high power needed for adequate mixing. Apart from the strain on the mixing machinery and the difficulty of working such compounds on rolls, it is difficult to control the temperature reached during mixing. This tendency to develop excessive heat during processing brings with it a danger of "scorching", especially if rapid acceleration systems are used. Also, such materials have a reduced flow in moulds. It follows, therefore, that such compounds have a limited application.

In recent years two methods have been developed to overcome this situation and to extend the range of rubber-based materials.

A.—Co-polymers of styrene such as styrene/butadiene are now available which, when compounded with rubbers and taken to the soft cure stage, yield a product of increased hardness and modulus. The processing qualities are greatly improved and the product has a low specific gravity. Such compounds can be made to possess leathery characteristics. The improved processing is due to the fact that the co-polymer resin is soft at processing temperatures and blends into the rubber phase completely, helping it to mix with the other components more readily.

B.—It has long been felt that great benefits would accrue from combining the properties of phenolic resins and rubber, but in the past difficulties in physically combining the two materials prevented progress. Now resins and techniques have been developed which enable semi-hard rubber products to be produced incorporating phenolic type resins. Resins are now available which blend readily with

Fig. 1.—Automatic weighing of ingredients on the operating platform of the Banbury mixer.

Fig. 2.—Operating platform of the Banbury mixer. The temperature recording instruments are seen immediately behind the operator.

natural and synthetic rubbers and which can be cured by means of hexa simultaneously with the cure of the rubber to produce products with higher hardness and tensile strength than soft rubber products having the same sulphur content. These phenolic resins also improve processing qualities, helping to keep the temperature under control during the mixing process and assisting in the dispersion of the ingredients of the mix.

Semi-hard or toughened rubbers based on the above two basic types are now widely used in the form of shoe-soling, flooring, factory work containers, and so on.

BATTERY CONTAINERS.

Battery containers have for many years been made in hard rubber of the conventional type, using blends of raw and reclaim rubber with fillers and a high sulphur ratio. They are also being produced in various compositions based on coal-tar pitch, bitumen, or asphalt as binder, with asbestos or cotton for reinforcement. The main requirements of a battery container are :

(1) Acid resistance.
(2) Impact strength.
(3) Rigidity.
(4) Heat resistance.
(5) Light weight.
(6) Low cost.
(7) Oil and petrol resistance.

The different materials already in use combine these properties in various ways. For special applications some use has been made of high impact styrene co-polymers and polythene. The progress in rubber technology, as outlined above, has led to further study of the requirements for battery containers and it is now possible to improve on the impact strength and heat resistance of the hard rubber containers while reducing their specific gravity and dimensions and still retaining adequate rigidity. Materials have been developed along these lines by the G.E.C. working under patents of the Richardson Company, and these materials have been given the name " Im-Plast ".

In developing these new " Im-Plast " materials consideration has been given to :

(1) Producing a material and a container with emphasis on maximum economy in weight and dimensions, with a view to enabling car and battery designers to take full advantage of the recent advances in rubber technology.

(2) Producing a material and container for replacement of existing types where certain external sizes must be preserved.

The development of these materials presented several problems :

(1) A suitable balance had to be achieved between the various methods of hardening the rubber compound, viz. vulcanisation, reinforcement with styrene co-polymers, and the incorporation of phenolic type resins and hardeners.

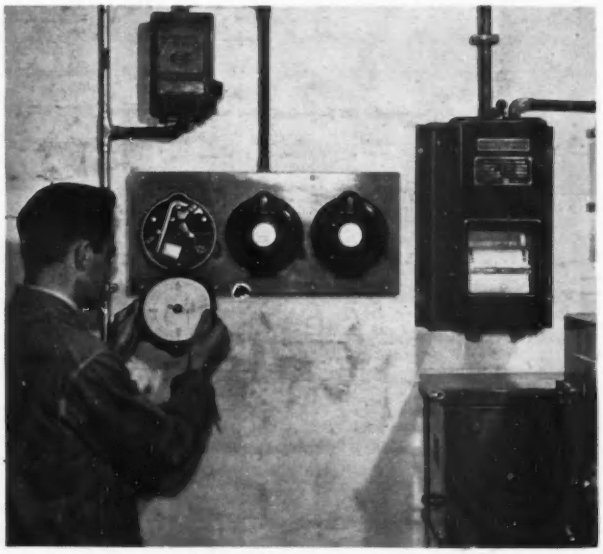
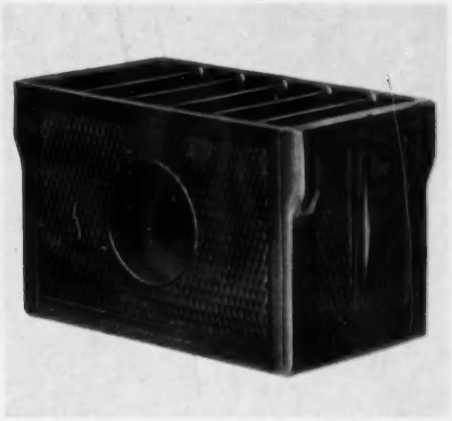


Fig. 3.—Process recording and power consumption instruments associated with the mixing plant.

Fig. 4 (left).—Removing an " Im-Plast " battery container from the moulding press. The timing unit is seen on the left and the temperature recorder on the right.

Fig. 5 (below).—An example from the range of containers.



(2) The filler content had to be studied exhaustively with regard to :

(*a*) Making best use of the reinforcing action of certain fillers, such as carbon black.

(*b*) Inertness to acid, with special reference to the leaching out of harmful materials such as manganese, chromium and iron.

(*c*) Total filler loading, which varies according to the types of fillers in use and affects processing qualities, physical properties and price.

(*d*) Specific gravity.

(3) Improved curing systems are now available through the use of organic accelerators, especially in combination, and these must be so arranged that they do not interfere with the curing of phenolic resins if these are also present.

(4) The rubber content may be provided in the form of raw rubber, or as reclaim of various types, or both. Reclaim helps to reduce the cost and speed up the cure, but its use in excess leads to some degradation of properties. Here again, therefore, a carefully considered balance must be achieved.

The original basis of " Im-Plast " materials was provided by the Richardson Company of Melrose Park, Illinois, U.S.A., and work along the lines discussed above has led to the development of two materials, " Im-Plast " and " Im-Plast 32 ". These materials are designed for new lightweight containers and for replacement of existing types respectively. Their principal properties are tabulated herewith :

	" *Im-Plast* 32 "	" *Im-Plast* "
Acid Resistance 1·250 S.G. acid at 60 deg. C. 28 days	Less than 20 mg. per sq. in.	Less than 20 mg. per sq. in.
Impact Strength		
B.S.S. 903	0·20-0·25 ft. lb.	Greater than 0·50 ft. lb.
2 lb. ball	15-25 in. lb.	>40 in. lb.
Hardness Shore D	66-68	70-75
Plastic Yield		
Ministry of Defence Specfn.	0·5-1 mm.	0·5-1 mm.
S.G.	1·27	1·23
Water Resistance		
7 days at 60 deg. C.	<1 per cent	<1 per cent

These materials are produced under licence from the Richardson Company's patents but have been modified by the G.E.C. to suit the requirements of the British market.

PRODUCTION CONTROL.

It is of the utmost importance in the manufacture of materials of this type that careful controls are established over the raw materials, and over their processing, storing and moulding. In the case of " Im-Plast " materials this control is established as follows :

(*a*) Raw materials are drawn only from sources which have proved reliable and consistent. They are examined and tested as necessary with particular

Fig. 6.—Impact testing of finished battery containers using the "drop-ball" method.

reference to such properties as particle size of fillers, acid resistance of fillers, resin viscosity and pH, water contents, curing rates, percentages of volatile materials, etc.

(*b*) The processing is carried out on a plant designed to provide the maximum of automatic controls in timing and temperature. Blending takes place at stages in the manufacturing process and automatic weighing is used in the handling of raw materials. Interlocking of the stages of manufacture through the electrical control system is arranged so that any failure in the sequence of operations at any stage of the process leads to an automatic shut-down of the whole plant in stages. A recording system is in operation so that any discrepancies in the conditions are recorded and the corresponding production can be located and checked as may be necessary (fig. 1, 2 and 3).

(*c*) The moulding procedure is also set up with precision in order to achieve the optimum in speed of cure and properties of product. Automatic control is therefore provided for the timing of the press operations, with a continuous record of temperatures (fig. 4). Provision is made for control of the pressure applied and temperature controls are available for the moulds. By these means, the optimum conditions can be established and maintained to yield fast production of high-quality boxes.

Fig. 7.—One of the 40 kV testing stations for flaw detection.

TESTING.

Testing (fig. 6 and 8) is carried out extensively on the mouldings in the belief that it is the final product which really counts rather than results obtained on separately-moulded test pieces prepared under laboratory conditions.

Impact strength is tested by means of a dropped ball test. This consists of an apparatus for dropping a 2 lb. steel ball from progressively greater heights until the box fractures. The test is applied approximately $\frac{5}{8}$ in. below the top edge of the box. Further information is obtained from test pieces cut from the boxes and tested in an Avery impact testing machine in accordance with B.S.903.

The hardness of the product is also an indication of consistency of quality and is continuously checked by means of a penetration needle test of the Durometer type.

Samples are cut from boxes at regular intervals for acid resistance tests. These are carried out in sulphuric acid of S.G. 1·250 at 60 deg. C. for 28 days. The increase in weight, the surface resistivity and the amounts of iron, manganese and chromium leached out are recorded and checked.

Finally, every box made is subjected to a 40,000 volt test between cells and from inside to outside of the box to detect any flaws which may occur (fig. 7).

From this brief survey it will be appreciated that new developments in rubber technology are being incorporated into the production of battery containers (fig. 5) to provide a high-quality product and to open up the possibility of new lightweight designs for the future.

Fig. 8.—Impact testing of notched specimens.

TECHNICAL LITERATURE

A digest of recent articles and papers by members of the G.E.C. and its associated companies

APPLICATIONS OF FERROELECTRIC DEVICES.

By E. E. Riches (Research Laboratories).

British Communications and Electronics, Vol. 4, pp. 214-219, April, 1957.

The author reviews the many and varied applications of ferroelectric devices of the barium titanate class, ranging from miniature capacitors and ultrasonic transducers to memory devices for electronic computers. A new development described in the article is the actuation of relay contacts by applying an electric field to electrostrictive barium titanate. Probable future trends in development are indicated which will extend the applications of ferroelectric devices in fields outside their use in capacitors and piezoelectric transducers, where they are already firmly established.

THE CONTRIBUTION OF LIGHTING TO MODERN LIFE (THREE CANTOR LECTURES).

By J. M. Waldram (Research Laboratories), C. Dykes-Brown (Illuminating Engineering Department, Head Office) and D. W. Durrant (Fittings Department, Head Office).

Journal of the Royal Society of Arts, Vol. 105, pp. 633-671, July, 1957.

Under the title of "Lighting in Outdoor Life and Work", Mr. Waldram's paper reviews typical ways in which artificial light has made possible, and is indispensable for maintaining, the whole of the varied existence of modern communities after dark in travel, at work and at play. Examples of practice in various parts of the world are given. Among the subjects discussed are airport lighting, street lighting and light signals on motor vehicles, floodlighting for marshalling yards and for sport, and lighting spectacles, both those of a specialised dramatic form like the French *Spectacles de Son et Lumière*, and decorative illuminations which appeal by their variety, ingenuity and extent.

Mr. C. Dykes-Brown's paper, "Lighting in Commerce and Industry", opens with a review of light sources and a discussion of economic factors. Points to be considered in deciding on the quantity and quality of illumination are discussed, together with the influence of interior colour schemes on the efficiency of lighting installations. The author deals with special problems of drawing office lighting, high bay lighting, colour matching and store lighting.

The paper on "Lighting in Decoration and Architecture", by Mr. D. W. Durrant, discusses the contribution of lighting to decorative art in interiors where the emphasis is primarily on relaxation and enjoyment. A review of basic factors in the theory of designing decorative interiors, showing how lighting may be used in conjunction with form, colour and texture of materials in building up the visual field, is followed by an analysis of various examples of the art in different types of interior.

PRINCIPLES OF THE LIGHT-AMPLIFIER AND ALLIED DEVICES.

By T. B. Tomlinson (Research Laboratories).

Journal of the British Institution of Radio Engineers, Vol. 17, pp. 141-154, March, 1957.

The paper first considers the necessary component parts of a light amplifying system and briefly points out the advantages of using solid state devices. A system is outlined which consists of a photoconducting layer in series with an electroluminescent phosphor layer. The properties of the constituent parts are discussed in detail and the behaviour of the series combination is examined. Various practical constructions are described and attention is drawn to the difficulties of manufacturing a picture-reproducing device of large area.

Optical feedback depends on the spectral emission distribution of the electroluminescent layer and the spectral response of the photoconductor. An amplifier with optical feedback such that the loop gain exceeds unity can be triggered by a light pulse and then remains in the light emitting condition until the supply voltage is reduced. Such an electro-optical binary switch is described using ZnS and CdS powder layers or single crystals. Complex combinations of such units could be employed in shift registers, scaling circuits, etc., and novel circuits are suggested which employ light as the means of triggering and coupling. These devices would be of miniature size and need few, if any, associated conventional components. Limitations of switching time and possible future developments are also discussed.

SEARCHING THE LITERATURE OF PHYSICAL AND INORGANIC CHEMISTRY.

By M. A. Short (Research Laboratories).

Research, Vol. 10, pp. 313-317, August, 1957.

A knowledge of the way in which the wealth of information contained in the literature of chemistry can be most quickly and thoroughly found, is a vital part of the education of a research chemist. Insufficient trouble is often taken to ascertain what work has been done previously in a chosen field, and this may lead to the expenditure of considerable effort in discovering some fact or method which was first reported months or years before. The article is intended to serve as a working guide to the literature for those engaged in studying the various branches of inorganic and physical chemistry and chemical physics; it is not intended to be a comprehensive guide for professional literature searchers.

THE VIEWING OF TELEVISION SCREENS (666).*

By R. D. Nixon (Research Laboratories).

Transactions of the Illuminating Engineering Society, Vol. 21, pp. 205-216, No. 8, 1956.

The paper discusses the available contrast ratio on television screens of the aluminised and non-aluminised types, and indicates the reduction in contrast due to direct illumination of the dark portions of the picture by the bright portions, halation in the glass envelope and external illumination. The results show that picture contrast ratio may be reduced by these effects from about 150 : 1 under the best conditions to 25 : 1 under typical domestic viewing conditions.

Experiments in television picture viewing with illuminated surrounds are described and curves given relating picture luminance with the surround luminance giving greatest viewing comfort for three sizes of surround.

DISCRIMINATOR DISTORTION IN FREQUENCY-MODULATION SYSTEMS (676).*

By R. G. Medhurst (Research Laboratories) and H. D. Hyamson.

I.E.E. Monograph 226R.

In a previous paper (Proc. I.E.E., 1954, Part 3, p. 171) expressions were obtained for the distortion of the modula-

tion when a frequency-modulated wave passes through a network whose group-delay and amplitude characteristics both exhibit small departures from constancy. An ideal discriminator network has the property that when it is fed with a frequency-modulated wave the amplitude modulation of the output is an exact copy (except for a scale factor) of the frequency modulation of the input. This can be achieved by a network whose group-delay characteristic is constant and whose amplitude characteristic is linear. In the present paper the theory given in the previous paper is extended to cover discriminator networks whose characteristics exhibit small departures from these ideal forms. Single-tone and noise-band modulations are considered. Two numerical examples are given, one being a design of 2-tuned-circuit discriminator, which is considered in relation to a 240-channel f.d.m. telephony system, and the other is an improved balanced discriminator suitable for a 600-channel system.

A METHOD OF CALCULATING FLUX FROM AN ISOCANDLE DIAGRAM USING A SYSTEM OF DISCRETE POINTS (686).*

By Doreen Smith (Research Laboratories).

Transactions of the Illuminating Engineering Society, Vol. 22, pp. 105-115, No. 4, 1957.

It is usual in this country to publish details of an asymmetric light distribution in the form of an isocandle diagram with additional information regarding total light output or flux in the upper and lower hemispheres. Sometimes it is also necessary to give utilisation factor curves for street-lighting lanterns. It is convenient to have a method of obtaining the information for these curves by quick calculation from the isocandle diagrams.

The flux represented on the whole or part of an isocandle diagram may be calculated by reading the intensity at a number of points in a carefully-chosen array and applying a simple formula. There is a number of different possible arrays and it is necessary to choose the one which is most suited to the particular calculation that has to be made. Two different types are described in this paper. One is suited to the calculation of the total light output of a lantern. The other is specially designed for the flux calculations involved in the production of utilisation factor curves.

DRIFT OF MINORITY CARRIERS IN THE PRESENCE OF TRAPPING (704).*

By A. K. Jonscher (Research Laboratories).

Proceedings of the Physical Society, B, Vol. 70, pp. 223-229, 1957.

A simple model of a semiconductor with one trapping level in equilibrium with one band only is defined through the lifetime τ and two trapping time constants τ_c and τ_t. A rectangular pulse of minority carriers is injected at one end and the drift of this pulse in a constant electric field is studied, neglecting diffusion effects. Analytical expressions are derived for the densities of free carriers N and of trapped carriers N_t, as functions of distance and time. Graphs are plotted of the time dependence of N at a collector point, corresponding to drift-decay measurements, and of the spatial distribution of N and N_t, at different times, which are relevant in photoconductive measurements. It is concluded that the attenuation of the drifting pulse corresponds to an apparent lifetime which is shorter than the true lifetime τ and that the shape of the (N_t time response) curve depends critically not only on the parameters τ, τ_c and τ_t but also on the distance of the collector point from the emitter and on the duration of the injecting pulse. In the case of heavy trapping most of the trapped and free charge is confined to the immediate neighbourhood of the emitter. In the steady state it is shown that, on this model, the density distribution of free carriers is entirely independent of trapping.

DISTORTION DUE TO THE MISMATCH OF TRANSISTORS IN PUSH-PULL AUDIO-FREQUENCY AMPLIFIERS (706).*

By K. W. Gurnett and R. A. Hilbourne (Research Laboratories).

I.E.E. Monograph 232R.

In a class B push-pull amplifier having balanced transformers, even-order harmonic distortion can be caused by differences in the characteristics of the two transistors. By considering the voltage gain of the two halves of the amplifier it is possible to obtain general expressions from which distortion caused by any particular characteristic can be calculated.

The paper is primarily concerned with audio-frequency amplification. It is necessary to consider harmonics outside this range because of the possibility of their giving rise to intermodulation products in the a.f. range.

The parameters giving rise to distortion can be divided into the frequency-independent and frequency-dependent types.

With regard to the frequency-independent parameters, the only significant factors are the current gain factor, the variation of base-collector current gain factor with emitter current and the extrinsic base resistance. In the case of the frequency-dependent parameters, which, in general, only become important at the higher audio frequencies, the significant factors are the collector capacitance, the variation of current gain with frequency and the carrier-storage effect.

In order to obtain low distortion, some matching of transistor characteristics is necessary. Methods are described whereby this can be achieved by fairly simple measurements.

Most of the work described in the paper is based on a low-power junction-type transistor. However, the methods used are quite general, and therefore applicable to other types of transistors.

INTERMODULATION DISTORTION DUE TO FADING IN FREQUENCY-MODULATION FREQUENCY-DIVISION MULTIPLEX TRUNK RADIO SYSTEMS (712).*

By R. G. Medhurst and Muriel Hodgkinson (Research Laboratories).

I.E.E. Monograph 240R.

Increased intermodulation distortion in frequency-modulation frequency-division multiplex trunk radio systems will be generated under fading conditions when the fade is due to the presence of one or more echoes. The distortion level is not simply related to the fading depth, but depends in a rather complicated way on the parameters of the echoes responsible for the fade. As a guide for future experimental work, theoretical investigation has been made of the nature of this dependence, both for single-echo and for multi-echo fading. In the latter case, a simple formula has been developed for the worst intermodulation distortion due to a system of echoes of given amplitudes and delay times. Numerical results are given for a particular 22·5dB fade whose echo structure was derived experimentally.

It is concluded that nothing can be deduced from measurements of fading depth alone about the magnitude of intermodulation distortion associated with fades generated by cancelling echoes. Measurements are required either of the parameters of the echoes or, directly, of the distortion.

EVAPORATION OF BARIUM FROM IMPREGNATED CATHODES (713).*

By I. Brodie and R. O. Jenkins (Research Laboratories).

Journal of Electronics, Vol. 2, First Series, pp. 457-476, March, 1957.

Recent developments in microwave beam devices have demanded cathodes which will withstand ion bombardment and provide higher d.c. emission densities than the conventional oxide cathode. These demands have been met by various forms of dispenser cathodes, of which the impregnated cathode introduced by Levi, in which the pores of

the tungsten are filled with a stable barium compound such as barium aluminate, is considered in this paper. Measurements made on a number of impregnated cathodes are described. In particular the evaporation of barium using a number of different impregnants has been measured and it has been possible to correlate the results with those obtained in 'L' cathodes and to postulate some of the mechanisms taking place within the cathode.

REPRESENTATION OF CURRENTS IN CONTINUOUS TANK FURNACES BY MEANS OF SMALL-SCALE MODELS.

By P. A. Michaels (Research Laboratories).

Journal of the Society of Glass Technology, Vol. 40, pp. 470T-481T, October, 1956.

A number of successful experiments have been reported with scale models of glass tank furnaces. On the other hand, it has been shown on theoretical grounds that a model with full dynamic similarity is unattainable. This apparent contradiction is discussed with particular reference to the problem of constructing a valid and useful model, and the approximations involved in making such a model, and its limitations, are examined.

AN IMPROVED DESIGN PROCEDURE FOR THE MULTI-SECTION GENERALISED MICRO-WAVE FILTER (718).*

By R. Levy (Research Laboratories).

I.E.E. Monograph 233R.

A highly accurate expression for the Q-factor of a direct-coupled filter is derived which is analogous to that for an associated quarter-wave-coupled filter. Existing theories usually consider filters of either the maximally-flat or the Chebyshev type, and it is shown directly, by transmission-line methods, that these are special cases of a generalised symmetrical filter. Design formulae are given for the bandwidth, pass-band tolerance, and the attenuation in the rejection band both for quarter-wave-coupled and direct-coupled generalised filters.

*** A limited number of reprints is available of those papers marked with an asterisk. Copies may be obtained on application to the Editor, G.E.C. Journal, Magnet House, Kingsway, W.C.2.**